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A Comprehensive Copper Compliance Strategy: Implementing Regulatory Guidance at Pearl Harbor Naval Shipyard & Intermediate Maintenance Facility

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ADMINISTRATIVE INFORMATION

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EXECUTIVE SUMMARY

OBJECTIVE

Studies were performed to develop a new National Pollution Discharge Elimination Systems (NPDES) Permit for the discharge of effluents from the Pearl Harbor Naval Shipyard and Intermediate Maintenance Facility (PHNSY&IMF or the Shipyard) into Pearl Harbor. The technical approach adhered to proposed U.S. Environmental Protection Agency (USEPA) guidelines for the development and application of the following studies:

- Best Management Practices (BMP) Program
- Discharge characterization
- Water Effect Ratio (WER)
- Recalculation
- Translator

The purpose of the discharge characterization, or pollution pathway analysis (PPA), is to evaluate copper contamination that is contributing to the Shipyard NPDES effluents. The BMP program helps to reduce contaminant loads and protect water quality through contaminant source identification and reduction. The objective of the WER and recalculation studies is the development of site-specific criteria or Water Quality Criteria (WQC) that are protective of the environment and consider ambient regional conditions. The translator converts ambient WQC, expressed as dissolved metal (DM), to a permit limit expressed as total recoverable metal (TRM). See Figure ES-1.

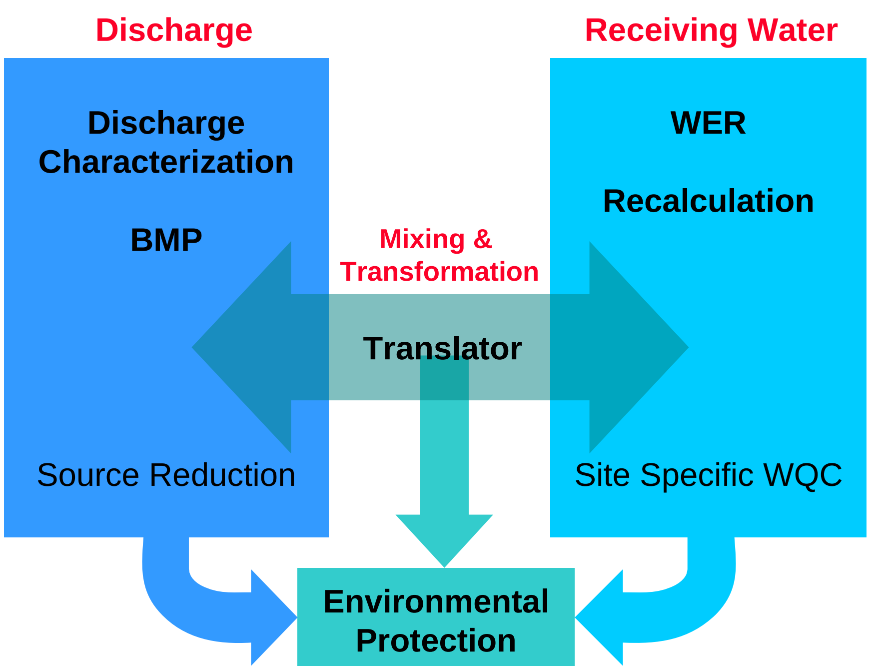

Figure ES-1. Technical approach for the development of a NPDES copper permit limit for effluents from PHNSY&IMF.

The results from these studies are combined with the Cornell Mixing Zone Expert System (CORMIX) hydrodynamic modeling runs to define a 15-foot zone of initial dilution, where the discharge is dominated by turbulence associated with mixing and the ambient receiving water is permitted to exceed acute criteria. The combined results of this comprehensive study can be expressed in the following formula, which expresses a new permit limit in TRM.

$$\text{Permit Limit}_{\text{TRM}} = \frac{(\text{Recalc WQC}_{\text{DM}})*(\text{WER}_{\text{DM}})*(\text{DC})}{(\text{CT})} \qquad (1)$$

Equation 1. In this formula, the Recalculation of Water Quality Criteria (Recalc WQC) is expressed as dissolved metals (DM) and multiplied by the WER, also expressed as DM, which is multiplied by a Dilution Credit (DC); the product of these three values then are divided by the Chemical Translator (CT), resulting in a final Permit Limit.

RESULTS

Discharge Characterization

The complex industrial setting at Naval Shipyards and the assortment of waters sources used there, is evident in the variability of metal concentrations and mass loads in their effluents (Gauthier, et al., 2000). This variability is exacerbated by temporal fluctuations of the input water sources, weather patterns, and contributions from five major streams into the Pearl Harbor Estuary. Ultimately, the copper loading in effluents from shipyards is influenced by the resuspension of particles from dry dock surfaces during rain events. While the background copper load associated with rainwater is insignificant (0.3368 µg/L Cu, n = 68, Kieber et al., 2004), resuspension of particles in the shipyard resulted in the highest copper loads measured during this study. The average (±1 standard deviation) copper concentration in the effluent tripled to 77.1 ±21.3 µg/L (n = 2) during rain events, compared to the copper concentrations of 22.7 ±9.7 µg/L (n = 12) measured during dry conditions. These results indicate that controlling rain runoff and keeping the dry dock free of particles should yield lower copper concentrations and loads in the effluent.

Of the five water sources identified in the Shipyard, non-contact cooling water is a constant source of copper to the NPDES sampling point (effluent) and is responsible for the majority of daily loading to the effluent. The other four sources are seawater intake, freshwater cooling, groundwater seepage, and rain runoff. Groundwater seepage and freshwater cooling are the two sources with minimal copper contributions in the total effluent. Seawater intake by volume is the larger source; however. it does not contribute to the effluent per se, but is the source for cooling water. Sampling seawater intake was a problem, and the most accurate measurements indicate a copper concentration of 15.1 ±8.9 µg/L. This value does not compare well to ambient harbor conditions (~1 µg/L), which is attributed to the proximity of the intake channel to vessels (with copper antifouling coatings) and other localized sources. The cooling water discharge had an average concentration of 23.2 ±14.9 µg/L, which is very similar to that in the NPDES sampling effluent of 22.7 ±9.7 µg/L in dry conditions. This similarity indicates that cooling water is the primary contributor to the copper load in the effluent during dry conditions.

Preliminary mass balance calculations also substantiated the predominance of non-contact cooling water in dry conditions and rain runoff in wet conditions as the major sources of copper loading in the effluent. These calculations were conducted with estimated flows, as these were not measured. However, the results attest to the importance of reducing particles in the dry docks under any circumstance.

In dry conditions, non-contact cooling water accounts for approximately 92% of the total copper loading in dry docks 1, 2, and 3, and 73% in dry dock 4. During wet conditions, it is estimated that runoff into the dry docks and discharges from the floor and sumps of the dry docks accounts for 80% of the copper loading in dry docks 1, 2, and 3, and 73% in dry dock 4. These estimates indicate that controlling particles in the floors, walls, and drainage system of the dry docks have the potential to reduce the copper load in the effluent.

Unsafe copper levels have not been observed in Pearl Harbor as a result of the current copper loadings into the water body. Dissolved copper concentrations measured in this effort had an overall mean of 0.62 ±0.25 µg/L. The highest concentration was observed from a sample taken during a rain event and did not exceed 1.3 µg/L. These concentrations were less than half of the current Hawaii WQS (2.9 µg/L) and well below the current acute USEPA WQC (4.8 µg/L). The nontoxic effect of these low dissolved copper concentrations was corroborated by the absence of ambient toxicity in all samples and for all species examined throughout this study. These results indicate that copper loadings to Pearl Harbor do not create impaired conditions.

Best Management Practices

Best Management Practices (BMPs) are activities taken to reduce contaminant loads and protect water quality. The most effective BMPs at the Shipyard are already being implemented in pollution prevention (P^2), with the specific goal of reducing contaminant contributions to the Shipyard effluents. Particles are the most important factor contributing to the high copper load in the effluent. Current BMPs include inspection and cleaning of drainage systems and efforts to reduce sediment and particle loads in the dry docks. This effort should be supported by removal of excess sediments from the sumps and dry dock channels throughout any ongoing operations, as well as more frequent cleaning of the drainage tunnels and sumps that service the drainage system.

The on-site analytical laboratory (Code 134) and the environmental department should collaborate to develop a monitoring strategy to evaluate the success of BMPs at the Shipyard. Sampling should be performed to support the evaluation and understanding of the effectiveness of BMPs. Multiple samples can be taken within the systems and timed according to the application of an individual BMP. Code 134 should develop and refine trace-metal analytical capabilities, using the analytical equipment already available at the Shipyard. This program is integral to evaluating the effectiveness of proposed BMPs and is one of the most cost-effective means available to address P^2 and support shipyard operations.

The application of new BMPs for pollution control at the Shipyard should be based on a solid PPA, which is the most cost-effective means to meet increasingly stringent environmental regulations. As discharge regulations continue to require lower overall contaminant loading, it is incumbent on the Shipyard to manage resources to meet these requirements. Many simple and inexpensive BMPs including material substitutions, secondary containment and cleanup procedures have already been adopted at the Shipyard, which is a good indicator to the regulatory community that the Shipyard is making sincere efforts to control and reduce pollution at its discharges.

Copper Recalculation

The recalculation procedure (USEPA, 1994b) is a step-wise method that involves corrections, additions, and deletions to the national toxicity data set, rendering it more representative of species occurring at a specific site. This procedure was applied to derive a new copper permit limit for the Shipyard. The current criterion of 2.9 µg/L total recoverable copper (USEPA, 1984a) is the NPDES permit limit for discharges to Pearl Harbor (HIDOH, 2002). The recalculation procedure involves a step-wise method that includes corrections, additions, and deletions to the national toxicity data set, rendering it more representative of species occurring at the site. For Pearl Harbor, the procedure used a more comprehensive toxicity data set and involved one correction, three additions, and two deletions to that data set, which resulted in acute and chronic criteria of 7.8 and 5.0 µg/L dissolved copper, respectively. These criteria provide the level of protection intended by USEPA (USEPA, 1985a) for those facilities that discharge copper into Pearl Harbor. These results were used to determine the permit limit in accordance with Equation 1.

Water Effect Ratio

A WER uses standardized toxicity testing to quantify the difference in a metal's toxicity between site water and laboratory water, which results in a ratio that is subsequently multiplied by the national criterion to derive a site-specific criterion. The objective of a WER, therefore, is to modify the State WQS for a site-specific Water Quality Objective and establish new permit limits that reflect the protective requirements necessary for a permittee's receiving water body. A WER study was conducted using embryos of sensitive marine invertebrates as a means of deriving a site-specific WQC for copper (currently 2.9 µg total recoverable copper/L in the State of Hawaii) for Pearl Harbor. The investigation involved extensive toxicity testing associated with four sampling events at eight different locations throughout the harbor during March 2005 through May 2006. Based on USEPA guidance, the study used the Mediterranean mussel (*Mytilus galloprovincialis*) as the primary species and the purple sea urchin (*Strongylocentrotus purpuratus*) and the Pacific oyster (*Crassostrea gigas*) as secondary corroborative species. Final nominal, total recoverable, and dissolved WERs were 1.68, 1.69, and 1.40, respectively. These results indicate that Pearl Harbor waters provide significant protection to aquatic species relative to the baseline lab toxicity tests utilized for the development of the state and national standards (USEPA, 1985a).

Copper Translator

The translator is a conversion factor for ambient WQS, expressed as dissolved metal, and applied to a permit limit, which is expressed as total recoverable metal.

A suite of properties can influence the ratio of total to dissolved metal. For this study, the effects of water temperature, pH, salinity total suspended solids (TSS), total organic carbon (TOC), and dissolved organic carbon (DOC) on the partitioning of copper were examined. The difference in these characteristics between effluent and ambient waters was minimal. A significant portion of the difference was associated with analytical noise and diurnal tidal cycles. Most of these differences relate to freshwater intrusion and heat exchange procedures in the dry docks and are not considered a significant influence chemically or biologically. Furthermore, correlation of the translator to variables such as TSS, TOC, and DOC was insignificant.

The translator was calculated as the arithimatic mean of the measured values for 1:1 mixtures of effluent and ambient waters. The mean dissolved to total ratio (i.e., the translator) was 62% for copper, a percentage lower than USEPA's published default ratio of 83%. Therefore, a substantial portion of the total copper (38%) in the dry dock effluents entering Pearl Harbor is not in the dissolved fraction. These results were applied to the permit calculation process to convert the permit limit into total recoverable copper in accordance with Equation 1.

Dilution Credit

Incorporation of a dilution credit is the final step in evaluating the Shipyard NPDES discharges. This credit can be applied to end-of-pipe measurements that are made when reporting monthly discharge monitoring values. The modeling tool CORMIX, recommended by HIDOH and the State of Hawaii, was used to estimate a dilution credit factor of 2.8 (±1.4) that will occur at the edge of a 15-foot zone of initial dilution from the Shipyard outfalls. This zone of initial dilution was established to consider an area where receiving water is permitted to exceed acute criteria. Initial mixing is dominated by turbulence associated with the discharge.

PHNSY&IMF's complex shoreline features and ambient environmental conditions may prevent CORMIX from accurately predicting the dilution credit that is applied to the NPDES permit. To ensure compliance and accurate dilution credit calculations, a mixing zone/dye study must be conducted. A dye study will eliminate any uncertainty associated with the dilution credit calculated from the model results.

A dilution credit of 2.8 is used in the calculation of the new NPDES permit as a surrogate value, until the Shipyard completes a mixing zone study to establish the actual dilution credit at 15 feet. After the study is complete, the new dilution credit will be adopted into the permit to replace the CORMIX modeling result. These criteria will provide the level of protection and appropriate regulatory control over discharges to the environment intended for Pearl Harbor by USEPA (USEPA, 1985a).

RECOMMENDATIONS

In accordance with the PHNSY&IMF NPDES Permit number HI011230 dated 15 January 2002 (HIDOH, 2002), the Shipyard initiated a study to develop site-specific discharge limitations using appropriate methods and guidance documents from the USEPA. This study incorporates the results from a recalculation procedure (USEPA, 1994b), a WER Study (USEPA, 2001), a CT Study (USEPA, 1996a), and consideration of a DC that will be applied within 15 feet of the Shipyard outfalls.

Based on the data from the culmination of the four studies (Table ES-1) used to develop site specific discharge limitations, the recommended new NPDES discharge limits for copper (acute and chronic) are outlined below.

$$\text{Permit Limit}_{TRM} = \frac{(\text{Recalc WQC}_{DM})*(\text{WER}_{DM})*(\text{DC})}{(\text{CT})}$$

Table ES-1. Recalculation of RecalcWQC, WER, DC, and CT values for the acute and chronic designations of copper.

Values	Copper (acute)	Copper (chronic)
RecalcWQC_{DM}	7.8 µg/L	5.0 µg/L
WER_{DM}	1.42	1.42
DC	2.8	2.8
CT	0.62	0.62
Final Permit Limit	**50.0**	**32.1**

The copper limit is calculated as follows for the PHNSY&IMF is calculated as follows:

(7.8 µg/L)*(1.42)*(2.8)/(0.62) = 50.0 µg/L Total Recoverable Copper (acute)

(5.0 µg/L)*(1.42)*(2.8)/(0.62) = 32.1 µg/L Total Recoverable Copper (chronic)

The components that make up the final NPDES discharge limits are all based on sound, state-of-the-science approaches consistent with USEPA guidance (USEPA, 1985a). These new limits will enable the Shipyard to continue business and industrial operations, and will require constant attention to control contaminants entering the conveyance systems from Shipyard operations. However, these limits do not support a permit and disregard the approach; to maintain compliance with these low regulatory limits, the Shipyard must test and adopt new pollution prevention practices and constantly adjust to changing activities throughout the Shipyard. The application of these new limits increases the probability of compliance for the Shipyard; however, these new limits can be accomplished only through the Shipyard's constant vigilance and attention.

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ACRONYMS AND ABREVIATIONS

1 N	One Normal
A/C	Air Conditioning
ACR	Acute-to-Chronic Ratios
ANOVA	One-way analysis of variance
ASTM	American Society for Testing and Materials
BLM	Biotic Ligand Model
BMP	Best Management Practices
C	Central station
CASS4	Near-shore seawater reference material for trace metals
CCC	Continuous Criterion Concentration
CFR	Code of Federal Regulations
CH_4	Methane
CL	Confidence Limits
CMC	Criterion Maximum Concentration
CO_2	Carbon Dioxide
CORMIX	Cornell Mixing Zone Expert System
CT	Chemical Translator
CV	Coefficient of Variation
CV%	Coefficient of Variation Percentage
CWA	Clean Water Act
DC	Dilution Credit
DD	Dry Dock
DD4:C	Dry Dock 4:Central
DD2	Dry Dock 2
DD4	Dry Dock 4
DM	Dissolved Metal
DOC	Dissolved Organic Carbon
EC50	Median effects concentrations
EMS	Environmental Management System
EPA	Environmental Protection Agency
ERLN	Environmental Research Laboratory Naragansett
FACR	Final Acute-to-Chronic Ratio
FAV	Final Acute Value
GC	Seawater from the Granite Canyon Facility
GMAV	Genus Mean Acute Value
HDOH	Hawaii Department of Health
HDPE	High-Density Polyethylene
HI	Hawaii
HIDOH	State of Hawaii Department of Environmental Health Water Quality Branch
High PAC	High Pressure Air Compressors
HM	Hazardous Materials
HNO_3	Nitric Acid
HW	Hazardous Waste
IC50	The half maximal inhibitory concentration
KCl	Potassium Chloride

LC50	The concentration of the chemical that kills 50% of the test animals in a given time (usually four hours)
LC50, EC50, IC50	
LC50/EC50	The ratio of lethal effects concentration to median effects concentration
LOEC	Lowest Observable Effect Concentrations
MCT	Metal Chemical Translator
MGD	Million Gallons per Day
ML	Middle Loch Station
MPSL	Marine Pollution Studies Laboratory
MTS/IEEE	Marine Technology Society/Institute of Electrical and Electronics Engineers
N	North Station
NFR	Near-Field Region
NOAA	National Oceanic and Atmospheric Administration
NOEC	No Observable Effect Concentration
NPDES	National Pollution Discharge Elimination Systems
NUC	Naval Undersea Center, San Diego, CA
P^2	Pollution Prevention
PCB	Polychlorinated Biphenyls
PHLP	Pearl Harbor Legacy Project
PHNSY&IMF	Pearl Harbor Naval Shipyard and Intermediate Maintenance Facility
PM	Particulate Metal
PPA	Pollution Pathway Analysis
PSA	Potentiometric Stripping Analysis
PSU	Power Supply Unit
PVC	Poly Vinyl Chloride
PWC	Public Works
QA	Quality Assurance
QA/QC	Quality Assurance/Quality Control
Q-HNO_3	Quartz-still grade nitric acid
Recalc WQC	Recalculated Water Quality Criteria
Recalc WQC_{DM}	Recalculated Dissolved Metal Criterion
RMZ	Regulatory Mixing Zone
RSD	Relative Standard Deviation
S	South station
SD	Standard Deviation
SIO	Scripps Institution of Oceanography
SMAV	Species Mean Acute Value
SRM	Standard Reference Material
SSC San Diego	SPAWAR Systems Center San Diego
STGFAA	Stabilized Temperature Graphite Furnace Atomic Absorption
TCA	Total Copper Analyzer
TDZ	Toxic Dilution Zone
TMA	Trace Metals Analyzer
TMDL	Total Maximum Daily Load
TOC/DOC	Total and Dissolved Organic Carbon
TRM	Total Recoverable Metal
TSK	Trimmed Spearman Karber
TSS	Total Suspended Solids
UNH	University of New Hampshire

USEPA	United States Environmental Protection Agency
USFWS	United States Fish and Wildlife Service
V	Volume
V_f	Volume Filtered (L)
W	Weight
WEF	Water Environment Federation
WER	Water Effect Ratio
WET	Whole Effluent Toxicity
WL	West Loch Station
WLC	West Loch Channel station
WQC	Water Quality Criterion
WQS	Water Quality Standards
W_{tss}	Weight of Suspended Solids (mg)

SECTION 1

INTRODUCTION

In December 2001, the Environmental Office (Code 106.3) at Pearl Harbor Naval Shipyard and Intermediate Maintenance Facility (PHNSY&IMF or the Shipyard) contacted the Environmental Sciences Division (Code 2375) at SPAWAR Systems Center San Diego (SSC San Diego) to request technical assistance with compliance issues related to the State of Hawaii's issuance of a new National Pollution Discharge Elimination Systems (NPDES) Permit for the discharge of shipyard effluents to Pearl Harbor. The NPDES permit at the PHNSY&IMF was issued with a discharge limit of 2.9 µg/L for copper (HIDOH, 2002). The Shipyard determined that this regulatory limit was unattainable and presented a potential compliance issue at the Shipyard. The Shipyard contested the limit while they executed a comprehensive study to support a scientifically based derivation of their discharge limit for copper following United States Environmental Protection Agency (USEPA) guidance and initiated a preliminary assessment of their discharges and the harbor in order to support discussions with the State of Hawaii Department of Health (HIDOH). As a result of these preliminary studies, the Shipyard proposed a four-part technical approach to derive site-specific criteria or Water Quality Standards (WQS) for Pearl Harbor and to reduce copper loadings in the harbor. HIDOH agreed to issue "an interim set of requirements allowing the Shipyard to be excluded from immediate imposition of the proposed copper concentration limits."

OVERALL TECHNICAL APPROACH

The four part technical approach consisted of the following elements:

- Develop and implement an improved Best Management Practices (BMP) Program to target cost-effective means to significantly reduce copper loads from the Shipyard.
- Perform detailed characterization of Shipyard discharges for dissolved and total copper, using appropriate trace metal clean methods.
- Conduct Water Effect Ratio (WER) and Recalculation Procedures to derive site-specific water quality objectives for copper.
- Perform a chemical translator study, a method to derive a site-specific formula for converting between dissolved and total recoverable metals for copper.

When the study elements are combined, a new permit limit will be established and expressed as total recoverable metals (TRM). The limit is derived in the following manner: the Recalculation of Water Quality Criteria (Recalc WQC) expressed as dissolved metals (DM) multiplied by the WER expressed as dissolved metals, multiplied by any Dilution Credit (DC) divided by the Chemical Translator (CT). This is better expressed as a simple formula:

$$\text{Permit Limit}_{\text{TRM}} = \frac{(\text{Recalc WQC}_{\text{DM}})*(\text{WER}_{\text{DM}})*(\text{DC})}{(\text{CT})}$$

The following USEPA guidance documents for national water quality assessment and regulation to establish permit limits at the Shipyard were used in this approach:

- 1993 Metals Policy (Prothro Memo): "It is now the policy of the Office of Water that the use of dissolved metal to set and measure compliance with water quality standards is the recommended approach, because dissolved metal more closely approximates the bioavailable fraction of metal in the water column than does total recoverable metal."

- USEPA Memo: "Office of Water Policy and Technical Guidance on Interpretation and Implementation of Aquatic Life Metals Criteria" and 40 CFR 121.36(b)(1).
- EPA-823-B-94-001 (February 1994) promotes refined WQS based on site-specific receiving water characteristics and resident species (Water Effect Ratio, Recalculation, and the Resident Species Procedure).
- EPA 823-B-96-007 (1996) Translator Guidance for Conversion between Total Recoverable and Dissolved Metals.
- EPA 64 FR 58409 (October 29 1999) issued plans to revise copper criteria based on the Biotic Ligand Model to address bioavailability.

The recommendations and approaches within these guidance documents have been successfully implemented throughout the United States, promoting environmental stewardship and supporting scientifically defensible regulatory discharge limits. Numerous studies throughout the nation have examined the application of WERs to provide regulatory relief.[1] One of the earliest WER studies for copper in an urban harbor was the New York/New Jersey Harbor study. This study, which developed a site-specific WER, also increased the national criterion to the existing values for acute and chronic effects (USEPA, 1994a). Two other key studies in estuaries were conducted in San Francisco Bay and Hampton Roads (Norfolk) Harbor. The City of San Jose, California, funded the development of a Total Maximum Daily Load (TMDL) and the adoption of site-specific water quality objectives for copper (6.9 µg/L chronic, 10.8 µg/L acute) in the South San Francisco Bay (Mumley and Speare, 2002). This study was a successful example of adoption of site-specific water quality objectives. The Hampton Roads study was a comprehensive four-part project incorporating a WER, recalculation, translators, and mixing zones, completed by the Navy and implemented by the Virginia Department of Environmental Quality (CH2M HILL, 2000, 2002a, 2002b). As a result of these efforts, in 2004, the Virginia Department of Environmental Quality adopted a revised WQC for copper of 10.5 µg/L for chronic and 16.3 µg/L for acute. When combined in conjunction with the translator value, a site-specific recalculation and mixing zone dilution factor yielded waste load allocations for copper, which are achievable by Navy dry docks (Cotnoir, 2002).

REGULATORY FRAMEWORK

States are required to review their water quality standards every 3 years and to submit the results of their review to USEPA (CWA section 303(c)(1)). USEPA regional offices approve State standards if they are scientifically defensible and protective of designated uses (40 CFR § 131.11). The current State of Hawaii WQS is based on older data for copper, citing 2.9 µg/L for the acute (24-hour average) and chronic (4-day average) values. The current national USEPA recommended criteria for copper are 4.8 µg/L for acute and 3.1 µg/L for chronic (USEPA, 1995a). However, since the State of Hawaii WQS is more restrictive than the current national WQC, the USEPA defers to the State standards. The NPDES permit limits issued to the Shipyard are currently set by the State of Hawaii with no allowance for a zone of initial dilution, or any consideration of ambient harbor conditions. The goal of this comprehensive study is to apply USEPA-approved methods to calculate a scientifically based permit limit for copper discharges at the PHNSY&IMF to support ongoing industrial operations and to maintain and protect the designated uses of the harbor.

[1] R. Gauthier et al. 1999. "An Integrated Marine Environmental Compliance Program for Naval Shipyards: Phase II/III Report. Contact Ron Gauthier, SPAWAR Systems Center. San Diego, CA.

METHODS

The technical approach described in this document is designed to meet the Shipyard's compliance needs in a timely, technically sound, and cost-effective manner by employing the methods approved and recommended by the USEPA. In conjunction with the State of Hawaii Department of Environmental Health Water Quality Branch (HIDOH, 2002), the following guidance documents were used to establish the scientific principles and procedures to derive site-specific water quality criteria and maintain environmental protection standards.

- USEPA Technical Support Document for Water Quality-based Toxics Control, (USEPA, 1991)
- USEPA Interim Guidance on Determination and Use of Water Effect Ratios for Metals (USEPA, 1994b)
- USEPA Water Quality Standards Handbook: Second Edition (USEPA, 1994c)
- The Metals Translator: Guidance for Calculating a Total Recoverable Permit Limit from a Dissolved Criterion (USEPA, 1996a)
- USEPA Streamlined Water Effect Ratio Procedure for Discharges of Copper (USEPA, 2001)

FIELD METHODS

Water samples were collected for three main purposes:

1. Support a harbor-wide, site-specific WER.
2. Establish a site-specific translator examining the partitioning of copper after effluents enter into and mix with ambient receiving water.
3. Characterize the potential range of concentrations of shipyard discharges and the effects of temporal variability in the receiving waters.

Samples were taken during four scheduled events:

- 15–18 March 2005
- 18–20 October 2005
- 23–27 January 2006
- 15–19 May 2006

During the January sampling event, over 1.7 inches of rainfall was recorded throughout the week representing a rainy season set of samples. Table 1 lists all samples taken during these four sampling events. To refine the specific methodology used in the study, samples were obtained during three preliminary events and subsequently included in the overall analysis. To capture any variability in Shipyard operations as well as temporal variability, samples were spaced over several months. During the study, samples were collected from eight ambient stations throughout the harbor (Figure 1) over a 16-month period. Measurements at the north, central, and south sampling locations included samples taken at surface and depth locations to address any stratification in the water column. Various points within the PHNSY&IMF facility were sampled to characterize the nature and composition of the regulated NPDES discharge.

Water samples were collected using clean sampling techniques (USEPA, 1996b, Appendix A) and analyzed for total and dissolved copper using clean methods for trace metal analysis (USEPA, 1996b). Samples were taken at each ambient station to support toxicity tests (USEPA, 1994b) and other parameters measured at all sampling locations included total suspended solids (TSS), total and dissolved organic carbon (TOC/DOC), oxygen, salinity, temperature, and pH.

LABORATORY AND ANALYTICAL METHODS

Laboratory and analytical methods supported the following goals:

1. Evaluate effectiveness of BMP for pollution prevention at the Shipyard.
2. Perform a recalculation procedure supporting a site-specific copper water quality criterion in Pearl Harbor
3. Perform a mixing zone analysis.

Appendix A provides a more detailed description of the methods used in this study.

The recalculation procedure adhered to USEPA guidance (USEPA, 1994b) and used the most up-to-date USEPA national water quality toxicity database for criteria, supplemented with information data on important local species (Bishop Museum, 1998). The dilution credit analysis followed USEPA guidance (USEPA, 1990) and HIDOH requirements for the use and application of mixing zones (HIDOH, 2000).

Table 1. Overview of samples taken for supporting copper water compliance studies at PHNSY&IMF.

Event	March 15-18, 2005		October 18-20, 2005		January 23-27, 2006		May 15-19, 2006		Total Samples
Parameter	**Stations**	***Samples**	**Stations**	***Samples**	**Stations**	***Samples**	**Stations**	***Samples**	
Effluent Characterization									
Total Recoverable Cu	7	14	7	8	10	12	5	8	42
Dissolved Cu	7	14	7	8	10	12	5	8	42
Trace Metal Analysis	6	42	7	27	9	43	5	21	133
TSS	7	7	7	8	10	12	5	8	35
TOC	7	14	7	8	10	12	5	8	42
DOC	7	14	7	8	10	12	5	8	42
Diss. Oxygen	7	53	7	9	10	12	5	22	96
%Sat DO	7	53	7	9	10	12	5	22	96
Salinity	7	53	7	9	10	12	5	21	95
Temperature	7	159	7	21	10	30	5	64	274
Conductivity	7	53	7	9	10	12	5	22	96
pH	7	53	7	9	10	12	5	22	96
Translator Study									
Total Recoverable Cu	3	2	3	2	3	2	3	2	8
Dissolved Cu	3	2	3	2	3	2	3	2	8
Cu Complexation Capacity	3	2	3	2	3	2	3	2	8
TSS	3	2	3	2	3	2	3	2	8
Water Effect Ratio									
^WER Toxicity (Site water)	8	360	8	720	8	360	8	720	2160
^WER Toxicity (Lab water)	4	180	8	360	3	135	8	360	1035
^WER Dissolved Cu	8	120	8	120	8	110	8	120	470
^WER Total Recoverable Cu	8	120	8	120	8	110	8	120	470
Ambient Characterization									
Total Cu	11	10	11	11	11	11	14	14	46
Dissolved Cu	11	11	11	11	11	11	14	14	47
Cu Complexation Capacity	11	11	11	11	11	21	11	22	65
Trace Metal Analysis	0	0	8	14	6	13	11	38	65
TSS	11	11	11	11	11	11	11	11	44
TOC	11	11	11	11	11	11	11	11	44
DOC	11	11	11	11	11	11	11	11	44
Alkalinity	8	11	8	8	11	11	11	11	41
Diss. Oxygen	11	11	11	11	11	24	11	11	57
%Sat DO	11	11	11	11	11	11	11	11	44
Salinity	11	11	11	11	11	24	11	11	57
Temperature	11	11	11	33	11	33	11	11	88
Conductivity	11	11	11	11	11	24	11	11	57
pH	11	11	11	11	11	24	11	11	57
Free Cu, potential Cu units	11	11	11	11	11	11	11	11	44
Stormwater									
Same analysis as Effluent; sampled from rainwater					2	25			25
TOTAL									**4992**

* Samples- includes controls, different number of species, and # of replicates taken at site.

^The toxicity samples include different Cu concentrations plus the 5 replicates necessary to meet statistical requirements.

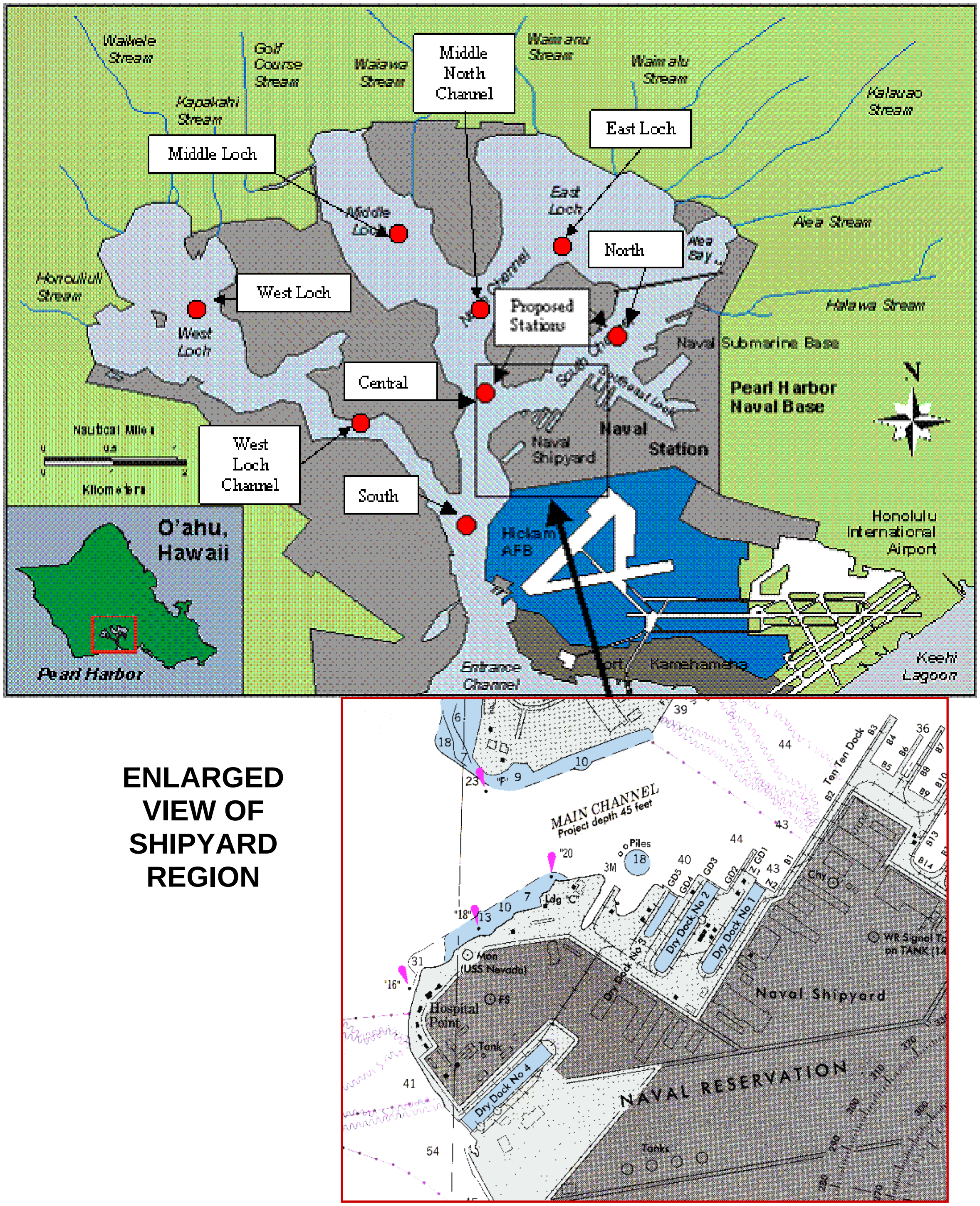


Figure 1. Sampling locations for water studies at PHNSY&IMF.

SECTION 2

EFFLUENT AND SOURCE CHARACTERIZATION

INTRODUCTION

As part of this study, an effluent and source characterization, or pollution pathway analysis (PPA), was performed to evaluate all sources of copper that are contributing to the Shipyard effluents. Five main streams flow into Pearl Harbor: Waikele, Waiawa, Halawa, Waimalu, and Kalauao.

Effluents from naval shipyards have high variability in metal concentrations and mass loads (Gauthier et al., 2000) partly because of the complex industrial setting in the dry docks and the variety of water input sources. These sources include entrained harbor sediments during a drydock cycling, seawater from adjacent bodies of water used for industrial purposes, freshwater from municipal sources, groundwater seepage from either or both seawater and freshwater sources, aeolian (wind- related) inputs, and storm water inputs. The complexity of the effects from these sources is exacerbated as they reach and flow on the floor of the dry dock, where they increase their copper loading by carrying copper-containing particles released by industrial processes and entrained sediments. Consequently, samples of the individual water source components of the PHNSY&IMF discharge were collected to address the range and temporal variability of their copper concentrations and their relative contribution in the total mass loading and concentration of the Shipyard discharges.

The goal of the effluent characterization was to evaluate and depict the various individual water sources or pathways (before mixing) contributing to the NPDES permitted outfall (or effluent). Each site visit included adjustments in the sampling based on the cumulative understanding gained from previous sampling events and ongoing Shipyard operations. This study provides a breakdown of copper concentrations and other parameters in the individual waste stream components to the dry dock discharge; however, measuring water flow rates for most water sources was impossible, which prevented determining the exact loading calculation from different sources into the effluent. However, it did provide evidence as to the main sources of copper contributing to the NPDES outfall. Study results are to be used to supplement developing and evaluating the BMPs discussed in Section 1. Finally, a preliminary mass-balance was calculated by assigning reasonable assumptions to the flow rates for the individual components.

METHODS

Source water samples taken to support the effluent characterization included samples of freshwater and seawater cooling, groundwater seepage/intrusion water from dry dock walls, pre-contact seawater intake for the firemain/cooling systems, rainwater runoff, and combined discharge samples (from NPDES sampling locations or effluent). The sampling took advantage of ongoing operations and intermittent activities such as freshwater cooling units and rain events to understand the relative contributions of these individual activities (Table 2).

Source water samples were collected using sampling protocols in USEPA Method 1669 (USEPA, 1996b, Appendix A) and analyzed for total and dissolved copper using clean methods for trace metal analysis (USEPA, 1996b), including the use of acid-cleaned apparatus and materials made up of polyethylene and “clean-hands/dirty-hands” techniques. Sample preservation, handling, and analysis were performed in a class-100 trace metal clean working area. Quartz still-grade nitric acid ($Q\text{-}HNO_3$) was added to the samples to decrease the pH to less than 2.

Table 2. Summary of effluent characterization samples from four sampling events.

Source Water Description	Total Number of Samples		
	Pre-process/ pre-contact waters	Process/waste-stream waters	Outfall discharges
NPDES sample points (effluent)	-	-	14 (4) *29*
Seawater Intake	9 (2) *15*	-	-
Groundwater seepage	9 (3) *15*	-	-
Cooling water	-	10 (4) *18*	-
Rain runoff	-	2 *6*	-
Freshwater cooling	-	(1)	-

Values in parentheses are from three preliminary sampling efforts and italicized values are from the TMA.

Copper concentrations were measured by stabilized temperature graphite furnace atomic absorption (STGFAA) spectroscopy by dilution and direct injection. The Standard Reference Material (SRM) SRM 1643d (trace metals in water) of the National Bureau of Standards was used to evaluate the precision and accuracy of the STGFAA analysis. Appendix B provides an example of the specific quality assurance/quality control procedures followed for the sampling and analysis events.

An automated trace metals analyzer (TMA) was also used during on-site visits to measure copper concentrations. The TMA measures the copper concentration in the sample by potentiometric stripping analysis. The analyzer can measure metals down to low parts-per-billion concentrations in near real time. This instrument allowed for on-the-spot measurements and greater characterization of samples. For each outfall and its associated upstream components, adequate characterization was based on a combination of traditional samples and TMA samples in a desired ratio of 1:4. Samples collected for on-site analysis by TMA were analyzed for total extractable metals at pH2, which were compared with the results from the laboratory STGFAA method.

The Shipyard has six outfalls associated with four dry docks (Figure 2). Dry docks 1 and 3 each have a single discharge point (outfalls 1 and 3, respectively), while dry docks 2 and 4 each have two discharge points (outfalls 2A, 2B, and 4A, 4B, respectively). Dry docks 1, 2, and 3 are cross-connected through a series of sumps and piping, with all effluents typically discharged from outfall 2A or 2B in a rotating manner to prevent excessive wear and tear. Outfall 4A and 4B are used alternately for dry dock 4 discharges. Representative effluents from these outfalls were sampled during the study.

Each traditional sample was characterized for two copper partitioning components: total recoverable metal (TRM) and dissolved metal (DM). Each sample must be split into two parts, one part to analyze for TRM and the other for DM (USEPA, 1996b).

Each sample was analyzed for ancillary parameters important to understanding the partitioning that occurs once the effluent mixes with receiving water, including TSS, TOC and DOC, dissolved oxygen, salinity, temperature, and pH. TSS and TOC/DOC were measured in the laboratory with discrete samples (USEPA, 1983). The other parameters were measured *in situ* with standard portable instruments.[2]

[2] B. Chadwick and J. Trefry. 1999. "Convention Center Dewatering Effluent Metal Translator." Unpublished Report for City of San Diego.

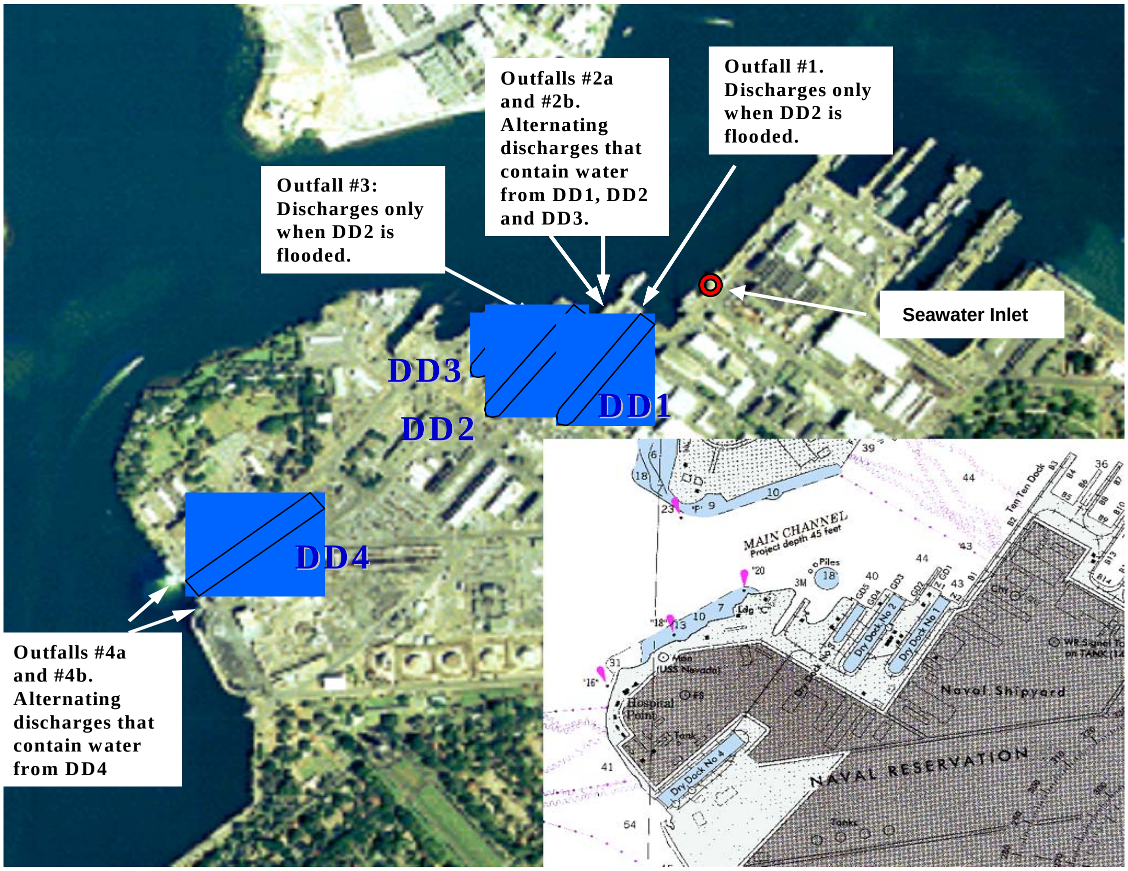


Figure 2. Diagram of dry docks and outfalls, and the location of the seawater inlet for the firemain.

The effluents/influents found in the samples are described below. Figure 3 is a diagram of their discharge into the dry docks:

Seawater intake is the Shipyard’s seawater supply system delivered via the firemain connection ports throughout the shipyard. This intake is used throughout the dry docks as temporary cooling water for vessels in dry docks and is the supply source for firefighting water. Samples from this location are before the seawater comes in contact with any ship systems or shipyard activities.

Freshwater cooling is non-contact cooling water used for temporary high-pressure air compressors (High PAC) and portable air-conditioning (A/C) units, collected after discharge from those units. This water is discharged directly to the drainage system on the floor of the dry dock. The source of this water is the Shipyard's potable/freshwater system. This system was only sampled once because it is infrequently used. This sample is from a preliminary sampling event in March 2003.

Cooling water is non-contact cooling water discharged from the ship's seawater systems. The source of this water is the Shipyard's seawater intake system (firemain), since the ship is not floating in seawater but sitting dry on the dry dock floor.

Groundwater seepage is seepage that enters the dry docks through cracks in the walls of the dry dock. This seepage is also discharged from PVC piping that drains the utility wells in dry docks 1, 2, and 3, and subterranean drain outlets discharging directly into the sumps at dry dock 4.

Rain runoff is effluent taken from the dry dock drain sumps (dry docks 2 or 4) during a storm event, representative of the combined operation-related drainage and the rainfall runoff.

NPDES sampling points (effluent) is effluent from the dry dock discharge outfalls. This discharge is from the drain pumps after the dry dock has been dewatered, not from the main dewatering pumps when the dock is emptied after being full. These sample locations are identical to the monthly NPDES samples.

RESULTS

There are multiple sources of copper to dry dock discharges. Some sources are steady, such as copper from the adjacent seawater body (used for cooling and fire fighting) and groundwater seepage into the dry docks (which can be either seawater or freshwater). Intermittent sources of copper include rain runoff, as well as freshwater or seawater used for industrial processes. Aside from the background or initial copper concentration in these water sources, copper loading can be affected as these waters flow through the dry dock conveyance system as the particle loading increases. The most likely source of particulate copper in dry docks is related to antifouling paints used on ship hulls. Cleaning and preparation of hull surfaces, the application of antifouling coatings, and residual sediments in the sump and drainage channels are all mechanisms that release particles with relatively high copper concentrations. These particles reach the floor and walls of the dry dock and are carried further by waters flowing across these surfaces.

Sporadic inputs of rain water are characterized by significant increases in loading in the effluent. While the inputs from rain are seasonal and sporadic, rain runoff greatly increases the total copper concentration and loading in the effluent, with the highest concentrations of copper in the effluents associated with rain events. Temporal distributions of total copper concentrations in five of the six types of water sources described in the Methods subsection are shown in Figure 3. This temporal distribution indicates that the largest concentrations of copper in the effluent correspond to those dates where there was rain runoff in the dry docks. The average (±1 standard deviation) total copper concentrations in the effluents in dry conditions are at 22.7 ±9.7 µg/L (n = 12); however, the effect of rain runoff significantly increases this average to 77.1 ±21.3 µg/L (n = 2) (Figure 4). The TMA measurements also indicate the steadiness in the copper concentration in dry conditions, with an average dry-condition copper concentration of 12.4 ±5.9 µg/L (n = 15), and an increase in copper in the effluent to an average of 25.9 ±15.8 µg/L (n = 14) in the wet sampling date, which includes the two highest TMA copper concentrations of 55.5 and 59.1 µg/L copper. These results indicate that controlling rain runoff or keeping the dry dock free of particles during the rainy season should result in lower copper concentrations and loads in the effluent.

Groundwater seepage and freshwater cooling are the two sources with minimal copper concentrations in the total effluent. As indicated in the Methods subsection, freshwater cooling was sampled only once, in March 2003, when it had a total copper concentration of 1.3 µg/L. Freshwater cooling only is intermittently used and has a very low associated volume; therefore, this discharge is not considered a significant source of copper loading in the dry docks.

Groundwater seepage illustrates the effects from different primary sources. Total copper concentrations in groundwater seepage had an overall mean of 2.63 ±2.67 µg/L (TMA 4.5 ±2.2 µg/L; n = 15); however, the average for dry dock 2 was 0.66 ±0.15 µg/L, while the dry dock 4 average was 4.20 ±2.69 µg/L. It is presumed that this difference in concentration for the two dry docks is due to the groundwater source, with a freshwater source for dry dock 2 (salinity of 5.0 ±0.36) and a seawater source for dry dock 4 (salinity of 31.7 ±0.97). Although groundwater seepage is a constant source of water to the dry docks, it has relatively low concentrations, minimal flow, and is not considered a significant source of copper in the effluent.

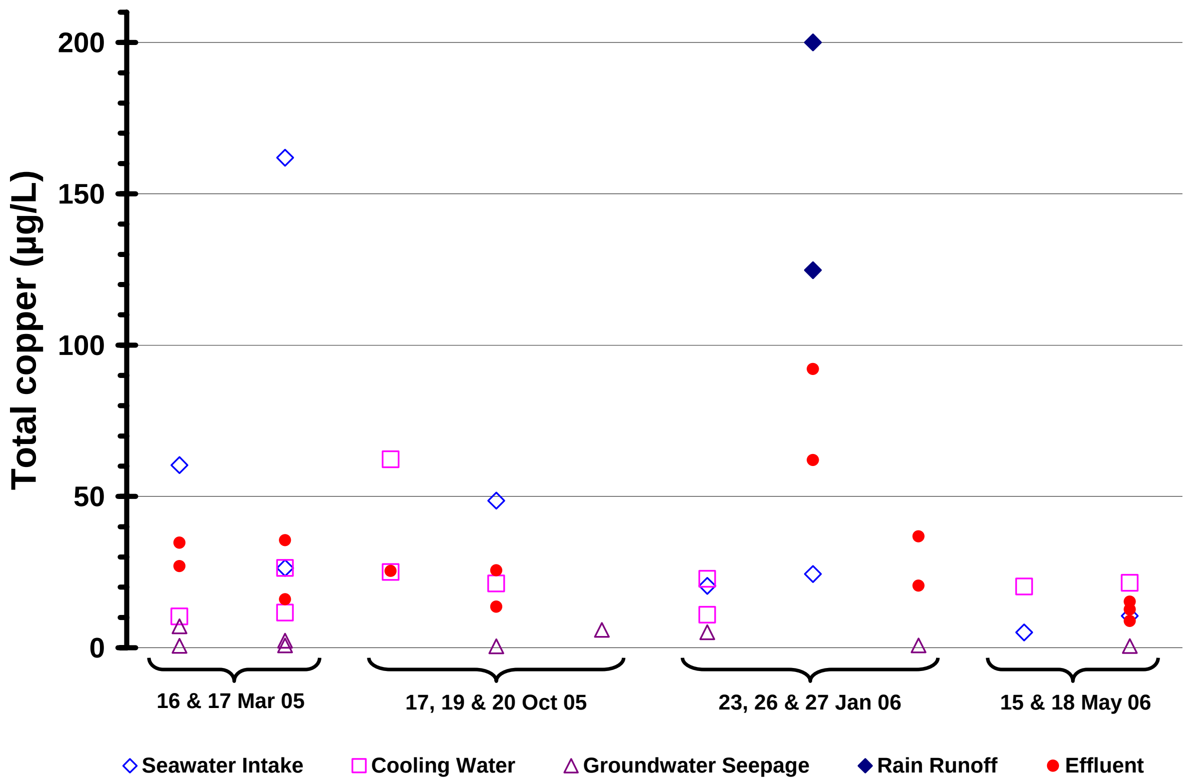


Figure 3. Total copper concentrations in five of the six types of effluents studied in PHNSY&IMF. Freshwater cooling is not shown; it had a 1.3 µg/L total copper concentration in March 2003.

Sampling contamination problems were experienced with seawater intake samples. Total and dissolved copper concentrations in these samples were inconsistent with those measured in the other sample types. As Figure 3 shows, of the six types of effluents, seawater intake had the greatest temporal variation in copper concentration. The concentrations measured at the beginning of the project are among the largest ones measured throughout the study (i.e., 162 µg/L on 17 March 2005; TMA 58.6 ±11.0 µg/L, n = 8 on 17 October 2005). But, these concentrations decreased over time to very low concentrations (i.e., 5.0 µg/L on 15 May 2006; TMA 5.7 ±1.6 µg/L, n = 6); this decrease in concentration is considered the result of contamination at the sampling port for this water and the improvement of cleanest sampling ports.

The plumbing for the seawater intake is pressurized steel pipe lined with concrete. The sampling ports are standard 5-inch connection brass (over 60% copper) fittings and valves designed to meet high flow and pressure requirements. To sample this high-pressure, high-flow system, a series of brass reducers was used to decrease the port diameter size to approximately ½ inch for connection to the sampling tubing. This decrease resulted in the seawater staying in the fittings for extended time periods, with the consequent leaching of copper as well as higher than normal design pressures applied to the reducer fittings during sampling, which caused erosion within the fittings. Experience from the preliminary sampling events was that sampling from these brass ports resulted in extremely high copper concentrations (622 µg/L total copper on 30 October 2002).

The strategy adopted was to set plastic hoses on these ports and to flush them for extended periods to reach concentrations representative of the water in the steel piping, not in the brass fittings. However, in practice, a suite of situations impeded the recovery of representative samples. Before the sampling events, personnel from PHNSY (Code 106.3) installed plastic hoses in the sampling port a couple of days before the sampling events and started flushing the system with a service tag indicating that the valve must remain open. However, personnel working in the dry docks did not follow the instructions and often closed the valves. Therefore, at the time of sampling, the ports were not ideal sample locations because the fittings were made with copper containing alloys, and they were not flushed enough to provide representative samples.

Over time, the system set-up and flushing was adjusted and better secured. During the last two official sampling events (January and May 2006), it appears that the samples were representative and consistent with copper concentrations within the system rather than a sampling artifact. This conclusion is mainly derived from the comparison to copper concentrations in harbor water used to feed the firemain system and on cooling water.

High copper concentrations in the seawater intake are not consistent with those in other water sources. Seawater from Pearl Harbor is fed through a pumping station to the seawater intake from a channel located under a dock in the Shipyard (Figure 2). The water in this channel was sampled and analyzed for copper concentrations three times for this effort. On 31 October 2002 (first preliminary sampling event), the total copper concentration was 1.47 µg/L. On 31 August 2003 (second preliminary sampling event), the sample had 1.5 µg/L. On 17 May 2006 (fourth official sampling event), it had 2.5 µg/L.

Therefore, an average concentration of 1.8 ±0.6 µg/L total copper was measured in the channel, which suggests a low copper concentration in the seawater intake and the ambient seawater. This average copper concentration corresponds to that measured with the TMA of 1.9 ±0.14 µg/L, n = 5.

Seawater intake pressurizes the firemain system. and cooling water is supplied from the firemain and flows through the cooling systems in the docked vessel, which suggests that total copper concentrations in seawater intake must be equal or lower than those in cooling water. Total copper concentrations in cooling water were relatively stable, with an average of 23.2 ±14.9 µg/L (TMA 18.7 ±5.9 µg/L, n = 18).

As mentioned above, these concentrations in seawater intake were very variable, with an average of 44.7 ±50.8 µg/L. This variability is mainly driven by the largest concentrations measured in the first two official sampling events. In contrast, the average concentration for the third and fourth official sampling events was 15.1 ±8.9 µg/L (TMA 17.5 ±10.3 µg/L, n = 15). This last value is in better agreement with the concentrations in the intake channel and the cooling water measured for this study.

Non-contact cooling water measurements indicate that it is a constant source of copper to the NPDES sampling point (effluent) and is responsible for the majority of daily loading to the effluent, as evidenced by the similarity of their total copper concentrations. An average total copper concentration in the effluent was 30.4 ±22.5 µg/L, and for cooling water was 23.2 ±14.9 µg/L. This similitude in their concentrations is exacerbated for the average effluent concentration of 22.7 ±9.7 µg/L when no rain is present. The conclusion that cooling water is the main source of copper to the effluent is further substantiated by field observations of cooling water flow to the dry docks.

Preliminary Mass Balance Calculations

Flow measurements of the individual sources were not available. However, estimates of the flow were made in accordance with published information and descriptions from personnel sampling and managing these sources. This preliminary estimate of mass balance would benefit from incorporating measured flow rates to improve accuracy. These estimated flows were used in combination with total copper concentrations in the various sources to create a preliminary mass balance of copper to the effluent (NPDES Sampling Point).

The mass balance is designed according to the setting of the discharges in the dry dock (Figure 4). The different water sources were sampled before they entered the dry dock and the combined effluent was sampled before it entered the harbor. Flow rates were estimated at individual sampling points. This process was designed to estimate the copper loading contributions from the floor and the sump in the dry dock.

For each water source, the copper loading was estimated from the daily flow rate and the average concentration measured in the corresponding samples. The combined effluent was treated as a single discharge, with copper loading calculated from the sum of the flows estimated for the individual water sources and the total copper concentration measured in the effluent. The percentage of contribution of each water source to effluent loading was calculated and the difference was attributed to loading that originated in the floor and the sump of the dry docks.

A "typical" dry dock condition was estimated for an average day. The mass balance was set to these conditions and presumed to be ongoing under dry and wet conditions. These conditions include the presence of one vessel in the dry dock, with freshwater cooling, cooling water, and groundwater seepage. The wet condition included a rain event. The same set of conditions was evaluated for dry docks 1, 2, and 3 combined and for dry dock 4 by itself.

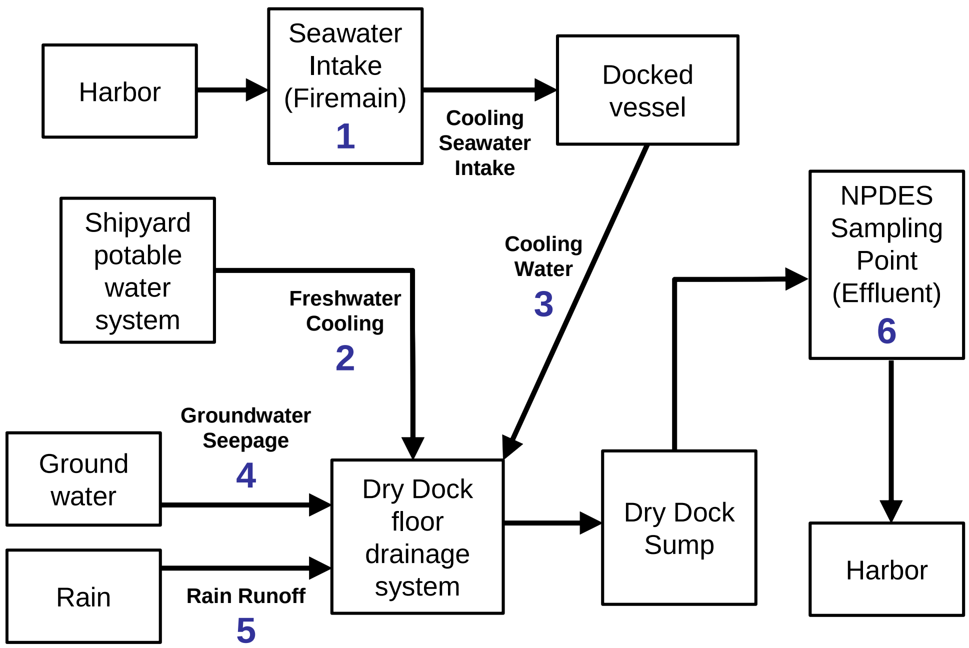


Figure 4. Flow chart of discharges sampled in dry docks. Numbers indicate sampling locations.

Considerations of flow rates included sampling personnel estimates, managerial estimates, and estimates from actual events. The calculated flow rate was used for "typical" and actual dry docks. Flow rate for the seawater intake (firemain) water source was not required as it only adds to the load as cooling water, which is estimated separately. The flow rate for freshwater cooling was visually estimated by personnel from SSC San Diego on 13 March 2003 as 50 gallons/minute in dry docks 2 and 4. The discharge was intermittent, and it was estimated that it was actively discharging for 1 hour each day. Flow rates for cooling water and groundwater seepage are estimated by managers at the dry docks from pump charts in the presence of docked vessels, and only when groundwater seepage is active.

Bruce Beckwith, Puget Sound Naval Shipyard Water Program Manager, and Glen Atta, PHNSY &IMF Water Program Manager, both indicated that based on their records, a flow rate of 1 million gallons per day (MGD) can be used for an estimate of cooling water for a docked submarine. For groundwater seepage, Mr. Atta said that a flow of 0.3 MGD was estimated in July 2005 for dry dock 2 and an average flow of 0.4 MGD was estimated from March, April, and May 2006 for dry dock 4. The average of these flows (3.5 MGD) was applied to the “typical” dry dock case.

Rain runoff was calculated as the volume of water delivered by 1.7 inches of rain falling on the surface of the dry docks’ floors and assuming dry docks 1, 2, and 3 as one unit, and dry dock 4 as a separate unit (corresponding to measured values on 26 January 2006). The average surface area was used for the loading estimates.

Copper concentrations in rainwater were adopted from Kieber, Skrabal, Smith, and Willey (2004), applying the average total copper concentration of 0.3368 µg/L in 68 samples of rainwater they collected in Wilmington, North Carolina, from 25 August 2000 to 24 September 2002. This concentration was applied because no regional data exist for copper concentrations in rainwater. The calculated flow rate was used for the ‘typical’ and actual dry dock situations as a one rain event only for the wet conditions situation. The flow rate for the effluent was calculated as the sum of the water sources characterized here, and the load was calculated with actual total copper measurements.

Loading from cooling water is the main source of copper for both dry and average conditions (Table 3). Mass-balance calculations indicate that cooling water loading could account from 56% in a “typical” average dry dock under average conditions to 92% of the total loading in the effluent of dry docks 1, 2, and 3 under dry conditions (Figure 5)

Table 3. Copper loading in the effluent estimated from each water source in PHNSY&IMF.

	Total copper concentration (µg/L)	Flow ($L \times 10^6$ /day)	Average Conditions Cu Load in Effluent (%)	Dry Conditions Cu Load in Effluent (%)	Wet Conditions Cu Load in Effluent (%)
	Typical Dry Dock				
Freshwater cooling	1.3	0.011	0.01	0.01	0.003
Cooling water	23.2	3.785	56	76	21
Groundwater seepage	2.6	1.325	2	3	0.8
Rainwater	0.337	0.432			0.03
Floor & sump			41	21	79
Effluent	30.4	5.121			
	Dry Docks 1, 2 & 3				
Freshwater cooling	1.3	0.011	0.004	0.01	0.001
Cooling water	22.4	11.355	66	92	20
Groundwater seepage	0.7	1.136	0.19	0.27	0.06
Rainwater	0.337	1.127			0.03
Floor and sump			34	8	80
Effluent	30.8	12.502			
	Dry Dock 4				
Freshwater cooling	1.3	0.011	0.01	0.01	0.004
Cooling water	24.0	3.785	57	73	25
Groundwater seepage	4.2	1.514	4	5	2
Rainwater	0.337	0.600			0.06
Floor and sump			39	22	73
Effluent	29.9	5.310			

In contrast, freshwater cooling accounts for 0.01% or less under any modeled condition, and groundwater seepage could only account for a maximum of 5% for dry dock 4 under dry conditions. These mass balance calculations indicate that particles in the floor and sump are an important source of copper to the effluent, and could account for copper concentrations from as low as 7.5% for dry docks 1, 2, and 3 under dry conditions to 41% in a typical dry dock under average conditions.

The contribution from the floor and sump to the total copper loading in the effluent is exacerbated during rainy conditions. The loading distribution is greatly affected by rain events, which decreases the loading contribution of all of the sources measured and greatly increases the contribution of the modeled source (Figures 6 and 7). The contribution by particles on the floor and sump of the dry dock, in average, could account for 79% (73 to 80%) of the total copper loading in rainy conditions. This estimate is supported by an average total copper concentration of 162 ±53 µg/L measured in a samples collected from the sump of dry docks 2 and 4 in rainy conditions. Controlling particle sources and loads to the floor and walls of the dry dock could be important in decreasing the copper loading in the effluent.

Copper concentration measurements with the TMA in the effluent support the increase in particulates discussed above. The average copper concentration measured with the TMA in the effluent was 18.9 ±13.3 µg/L, n = 29, which does not compare with the total copper concentration of 30.4 ±22.5 µg/L measured by STGFAA; however, this value agrees with the dissolved copper concentration of 15.7 ±8.0 µg/L, n = 13 measured with STGFAA.

The agreement of the TMA measurements with dissolved copper has been observed before. Blake, Chadwick, Zirino, and Rivera-Duarte (2004) indicated that the TMA measurement at pH 2 is more closely related to dissolved copper than to total copper, an artifact of the TMA analysis, which cannot detect copper associated with particles and ligands in solution. This agreement between dissolved copper and TMA, in contrast to the disagreement with total copper measurements, indicates an increase in particle loading in the effluent, and supports the submittal on controlling particle sources and loads in the conveyance system and sump in the dry docks.

CONCLUSION

Flushing of particles from the dry docks and resuspension of particles in the sump contribute to the copper loading from the dry docks. Industrial operations in the dry docks generate significant amounts of emissions, including particles and fluids (Kura and Tadimalla, 1999). These emissions could end up on the floors and walls of the dry docks and potentially be flushed into the sump and pumped out in the effluent. Containment of these emissions is covered extensively in the Shipyard BMP process, and the associated practices were observed in the field during this study.

Sediment intrusion during the flooding of the dry docks and long-term inputs from other sources accumulate in the sump at the bottom of the dry docks, which usually have a high concentration of particles. These factors can contribute to the copper loading in the effluent from the dry docks, which was evident in the demonstration of the total copper analyzer (TCA) in dry dock 2 at PHNSY&IMF.[3]

The TCA was set at PHNSY&IMF between 24 February and 8 April 2004. For the demonstration, the sampling port for the TCA was located above the sump at the bottom of the pump well, which is a six-story deep subterranean structure at the side of the dry dock, with pumping and controls for water and electrical systems. Water pumps were operated for 18 minutes every 2 hours to maintain the water level in the sump. This operation increased total recoverable copper concentrations up to 35 µg/L from a baseline concentration of about 20 µg/L every time the pump was activated (Figure 8), which is attributed to increased particulates in the effluent under pumping and subsequent settling.

These observations indicate that controlling particles on walls and floor of the dry docks, as well as in the sump, should substantially decrease in copper loading in the effluent. As discussed above, the main water source of copper to the effluent is cooling water. Arguably, the only possibility to decrease copper concentrations in cooling water is to continuously flush the seawater intake. Furthermore, as indicated by the measurements from the TCA, reducing the quantity of particles in the sump should decrease the total copper concentration in the effluents to levels similar to those in cooling water. This effect could be achieved by regular cleaning of the sump and continued pollution prevention efforts at the Shipyard to examine and control sources of particle contamination in the dry dock.

[3] I. Rivera-Durante, M. Putnam, and E. Arias. 2006. In Press. "Total Copper Analyzer for Rapid in situ Characterization of Effluent Discharges." Final Technical Report to the Environmental Security Technology Certification Program (ESTCP), p. 69. Contact Ignacio Rivera-Durante at SPAWAR Systems Center San Diego.

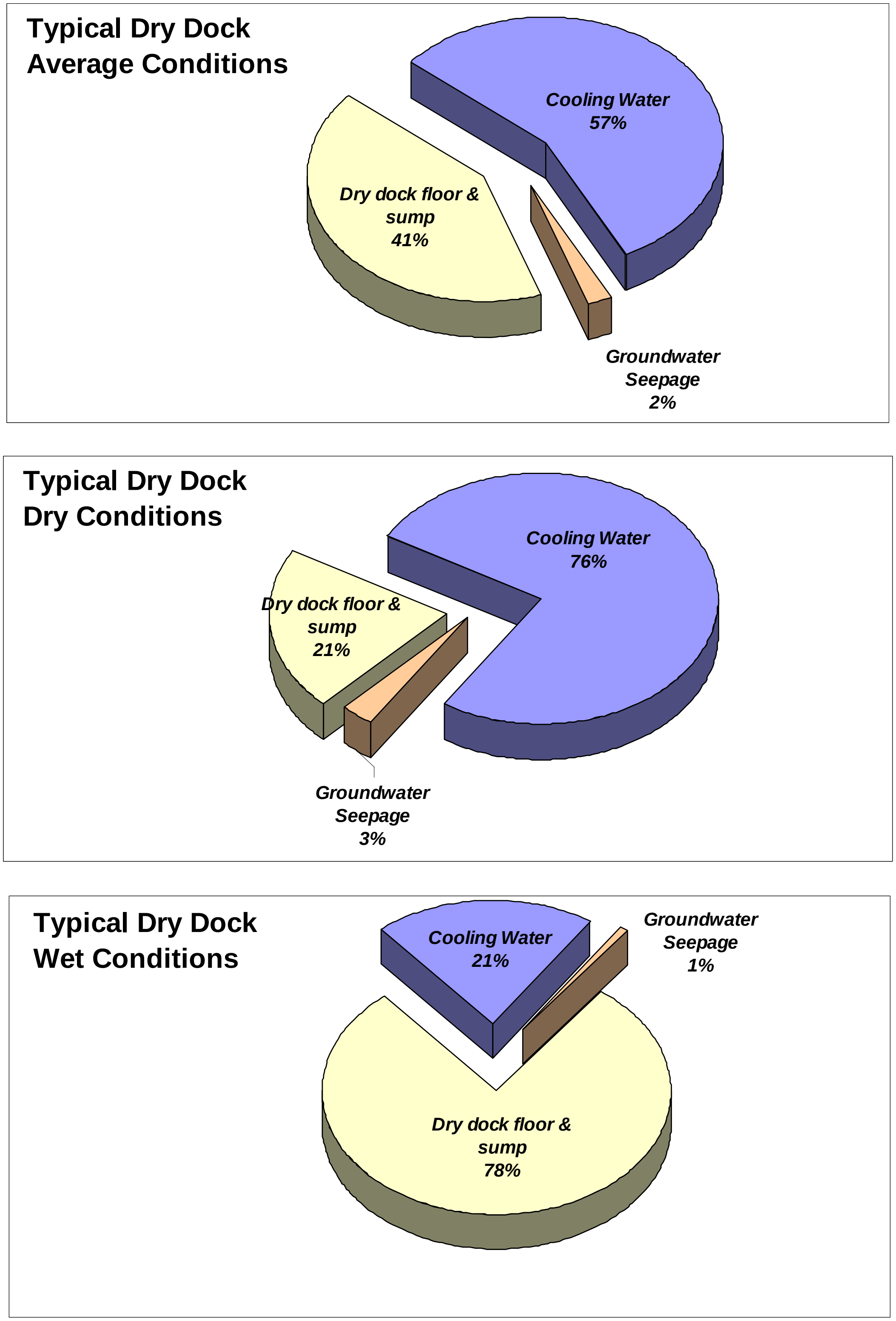


Figure 5. Mass balance calculations for typical dry dock conditions at PHNSY&IMF.

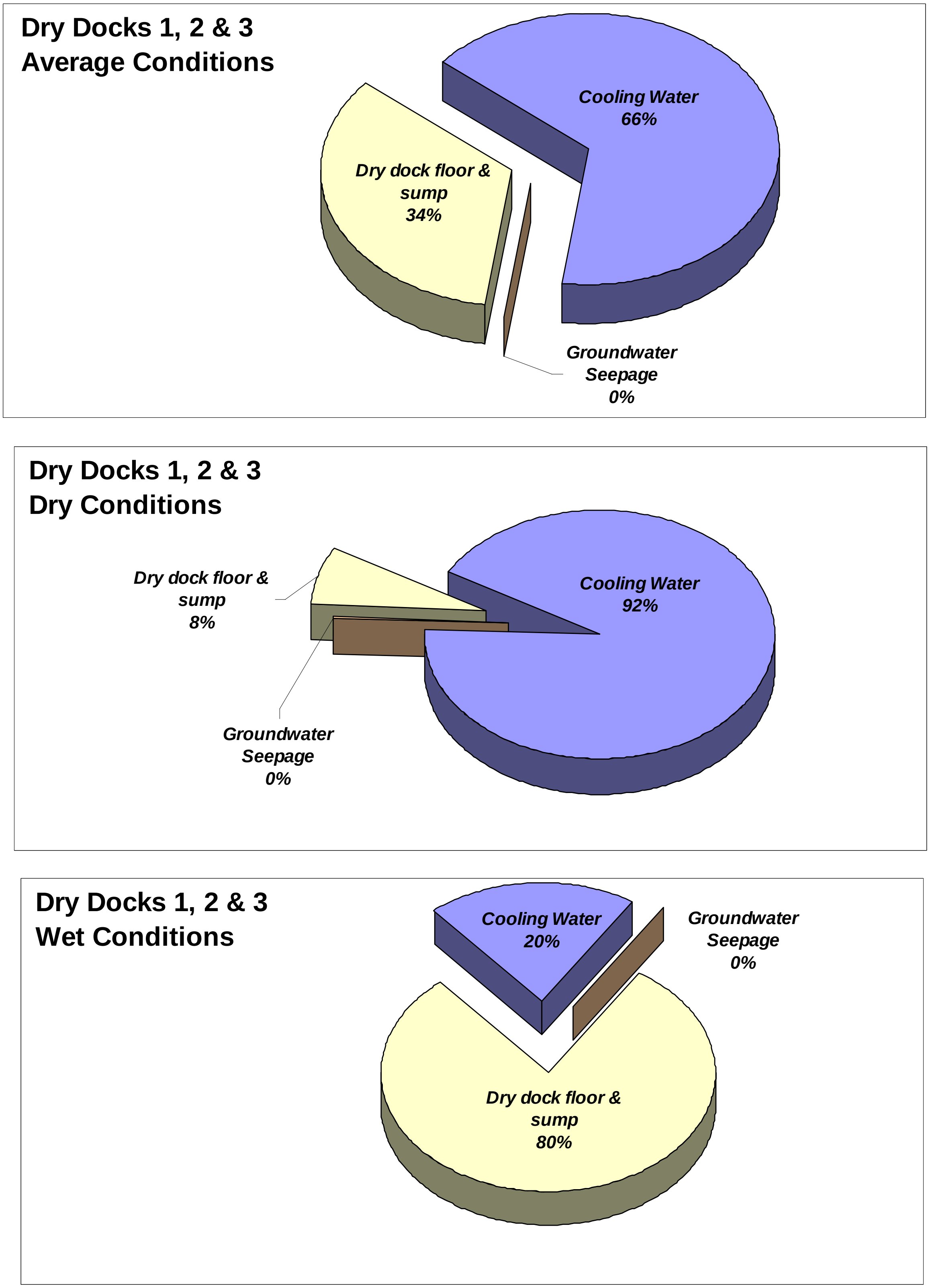
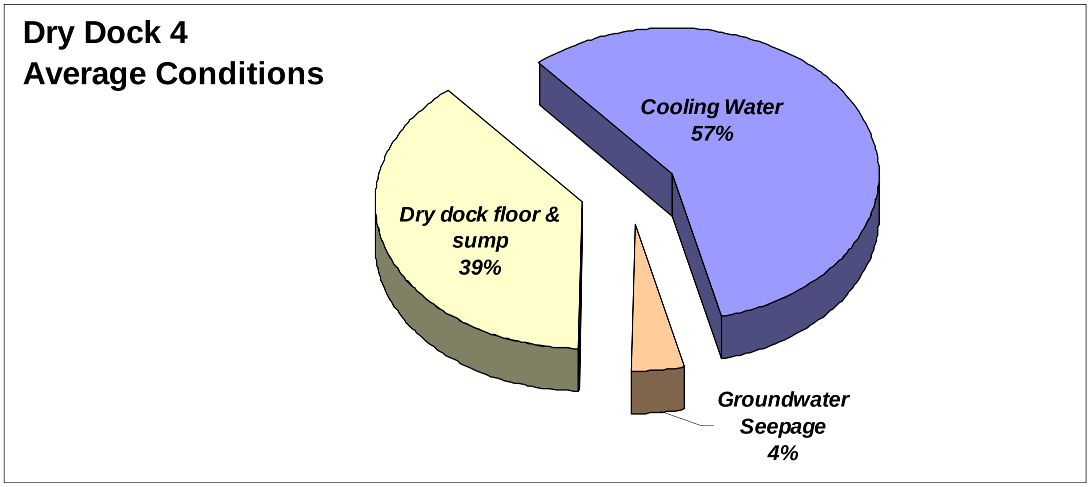
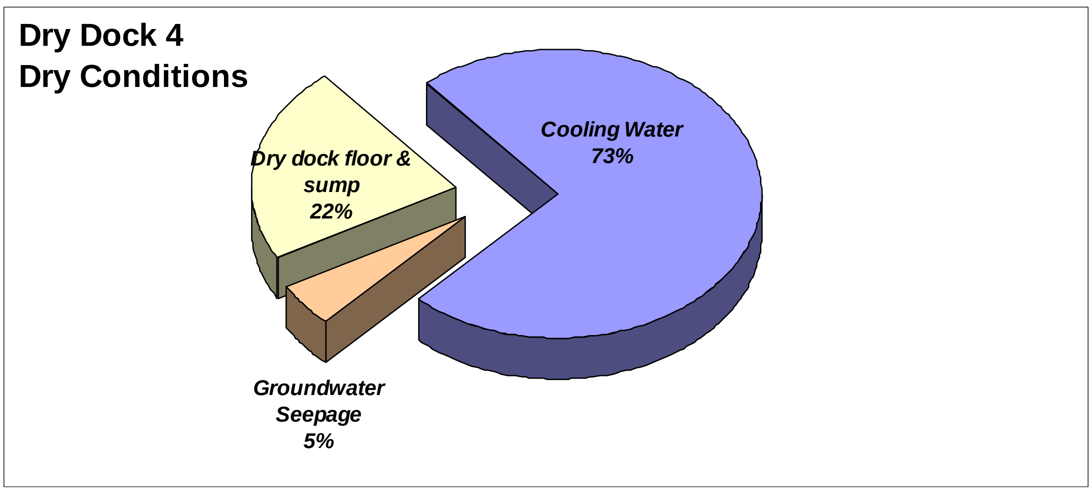


Figure 6. Mass balance calculations for dry docks 1, 2, and 3 at PHNSY&IMF.





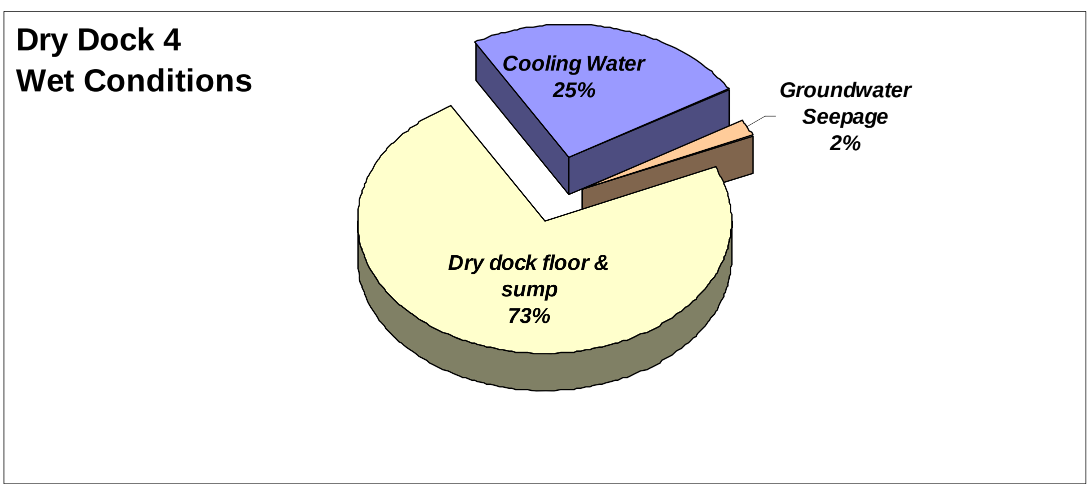


Figure 7. Mass balance calculations for dry dock 4 at PHNSY&IMF.

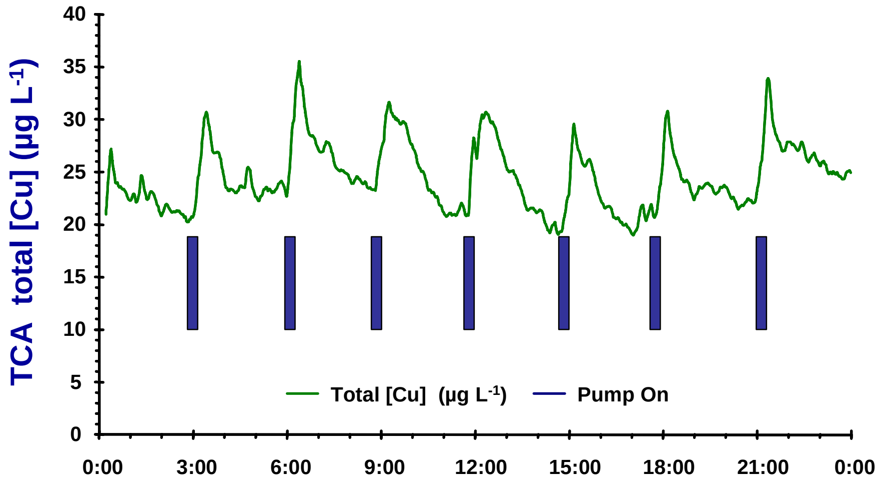


Figure 8. Response of the TCA to pumping in dry dock 2 at PHNSY&IMF.[4] An increase in total recoverable copper was observed every time the pump was activated, and a subsequent decrease is observed once the pump is deactivated.

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[4] Rivera-Durante et al., 2006.

SECTION 3

BEST MANAGEMENT PRACTICES PROGRAM

INTRODUCTION

Best Management Practices (BMPs) are activities undertaken to reduce contaminant loads and protect water quality. These activities can include methods, measures, or practices selected by a facility to meet its contaminant control needs. BMPs include but are not limited to structural and nonstructural controls and operation and maintenance procedures. BMPs can be applied before, during, and after pollution-producing activities to reduce or eliminate the introduction of pollutants into receiving waters.

BMPs fall into two general categories: source control and treatment. Source control is the most cost-effective means of reducing pollution and consists of operational practices that reduce pollutants at their source before they are introduced into the system. Treatment control BMPs are specific methods to treat or remove contaminants from waste streams and usually require facility modifications as well as a commitment of resources for effective implementation. Successful implementation of further BMP efforts at the Shipyard will improve the program to target cost-effective means of source and treatment control to reduce contaminant loads.

Integral to the BMP development process is an implementation action plan and a monitoring plan to track BMP effectiveness and goal attainment. BMP implementation requires planning and coordination, describing what is to be done, and when, how, where, and who will be doing the specific actions. A BMP is not worthwhile if it cannot be shown as effective; therefore, monitoring is an integral part of developing successful BMPs. Monitoring requires effective knowledge of what is to be measured, and how, where, and when such measurements should be made.

The most cost-effective means of controlling contaminant contributions to the environment at PHNSY&IMF is to examine the ongoing industrial and commercial activities through pollution pathway analysis (PPA) and then select the most appropriate pollution control management practices or BMPs to reduce available pollutant loads before they enter the harbor. PPA is a systematic process used to identify pollution sources, pathways, and loading into the environment. First, pollution sources and the Shipyard processes associated with those pollutants must be identified. Once identified, the pathways and quantities of these pollutants entering the environment must be established, which will allow pollution control efforts to be prioritized. Prioritization can be driven by factors such as regulatory compliance, worker safety concerns, cost savings considerations, or community concerns. These priorities determine BMP goals, which drive BMP development.

The Department of Health Hawaii requires that all discharges receive “the best degree of treatment or control” (HIDOH, 2004). To meet these requirements, the Shipyard has established BMPs to reduce contaminant contributions to various waste streams. The documented BMPs at the Shipyard were examined and compared to ongoing operations and activities within the Shipyard. A comprehensive search of other industrial practices was also conducted to find new or alternative practices that could be adopted by the Shipyard.

METHODS

Observations were made during seven separate visits to the Shipyard from October 2002 to May 2006 to gather PPA data and document and observe current BMPs, and to make recommendations to improve pollution prevention (P^2) practices. The PPA observations and data gathered from the site visits were combined with a comprehensive review of BMPs and ongoing programs throughout the Navy and shipyard industries. The goal was to make specific recommendations for new or improved BMPs at the Shipyard.

RESULTS AND DISCUSSION

Pollution protection is the most effective BMP implemented at the Shipyard. The goal of these efforts is regulatory compliance, specifically the reduction of contaminant contributions to the waste streams at the Shipyard. The Shipyard focuses its attention on industrial operations within the dry docks, particularly processes involving the hull of a vessel and its exterior coatings. Blasting, painting, grinding, welding, and similar operations are all controlled to ensure contaminants are captured before entering the Shipyard conveyance systems. All contractors that operate on shipyard property must follow a specific set of BMPs, including the use of drop cloths under areas where hull work is performed and covering open dry dock drain channels during painting and blasting operations as well as specific requirements to prevent airborne contaminants from entering the conveyance systems. Each time the Shipyard awards a new contract or allows a new contractor on Shipyard property to perform work, they must participate in a comprehensive briefing of environmental requirements. This environmental briefing includes specific BMPs and P^2 activities that the contractors (and their subcontractors) must follow.

Pollution Pathways

Reducing the particle load to the system is a difficult endeavor. Current BMP practices include inspection of dry dock drainage channels, sumps, trenches, cross-connection and conveyance channels (pathways) on a regular basis and removal of sediment, sludge, abrasives, and spent material, as necessary. Inspection and cleanout includes the stormwater drainage systems because such actions reduce residual contaminant environmental loading that can cause eventual long-term impacts. Several attempts have been made to install sediment traps and retain solids before entering the drainage system, including filters and various dry dock modifications.

These changes have met with varying degrees of success and are a continuous challenge because of operational and personnel requirements. Filters often impede the flow of water, which causes flooding up into other containment and work areas. Flooding increases the contaminant loads to the system and interferes with operations. Frequently, flow rates at the Shipyard are high during multiple operations and it is impractical to use screens or devices that limit the flow of wastewaters to maintain dry, clean, work surfaces.

The Shipyard continues to experiment with configurations that capture sediments and do not interfere with operations. The Shipyard is considering several additional procedures for BMP implementation, including additional contractor requirements and expenditures. These requirements would include pressure washing of the dry dock floor after paint removal operations as well as sweeping and cleaning of active work areas at the end of each work shift. According to Bruce Beckwith, Puget Sound Naval Shipyard Water Program Manager, a good sweeping and cleaning of the area is as effective as pressure washing, so this option should be carefully evaluated. The Shipyard has made specific changes to facilities to reduce or eliminate contaminant loads such as the replacement of copper shielding and drainage gutters with inert materials that do not contribute contaminants to the wastewater stream.

The operations within the dry docks are the major source of metals/contaminants to the shipyard conveyance systems. However, non-industrial sources also exist in the dry docks, such as groundwater intrusion. Alteration of the dry dock floors to segregate process wastewater and intrusion water at the Shipyard would require a large capital investment and multiple years to implement.

The results from the current studies indicate that groundwater intrusion contributes very little to the copper load in the Shipyard (see Section 1). Segregation of seepage water and process waste waters is effective when the docks have a significant portion of leakage/relief waters because of treatment costs associated with total volume. It is estimated that seepage and intrusion water contributes 0.06 to 5% of the total volume of discharges, depending on seasonal conditions, which makes this alternative less effective and more costly than other BMPs available to this facility.

Site visits at the Shipyard indicate that operations and maintenance activities occurring within the dry docks are the main source of the contaminants that end up on the dry dock floor. These contaminants are the major contributors to the high concentrations in the outfalls. Additional source control BMPs should be evaluated and implemented at the Shipyard to reduce the contaminant load from maintenance activities within the dry docks. This control will require specific attention to each individual activity because the BMPs that are currently used are already controlling most contaminants and additional BMPs may not be any more effective than existing ones. The challenge is to balance resources with effective solutions that will address small contributions of contaminants.

Non-contact seawater cooling (cooling water) from ships and submarines is the largest component of the total volume of discharge water. This water is ambient seawater that is drawn into the PWC firemain (or seawater intake) system, conveyed to the dry docks in a closed piping system, pumped through the ships for cooling, and then discharged into the (open) dry dock drainage channels. Sampling data indicate that until this cooling water hits the open discharge channel, it has a relatively low copper concentration. The Shipyard has been experimenting with using screens to reduce velocity and turbulence in the drainage channels and capture large pieces of trash. The screens are often bypassed during periods of high flow rates to avoid flooding of adjacent working areas in the dry dock floor.

Additional attention should be given to clean-up efforts between shifts and maintenance operations, particularly in the areas that are considered outside the established containment areas. More frequent interim cleaning of containment areas is also recommended. This consideration is important because stormwater events can contribute significant contaminant loads to the discharge because of their unpredictable nature. Finally, because of the nature of dry dock flooding/dewatering cycling, large amounts of residual sediments remain in dry dock sumps and cross-connection channels. Focused efforts to clean out and reduce sediment loading to these areas will help control chronic sources of contamination.

Monitoring

Understanding the effectiveness of various BMP options that are implemented is an important component of understanding pollution prevention and management strategies. A second category of BMPs is related to small changes to facilities and taking advantage of existing equipment and personnel. The Shipyard has an on-site chemistry laboratory that can provide a wide range of analyses and sample processing to help the Shipyard achieve regulatory compliance and evaluate the BMP success.

Combining this rapid assessment capability with regularly scheduled reviews of Shipyard inspection logs and cleaning records would allow problem areas to be easily identified and addressed. More efforts should focus on developing this program, as it is integral to evaluating the effectiveness of proposed BMPs and is one of the most cost-effective means available to address pollution prevention.

The chemistry laboratory and the environmental department should work together to develop an effective monitoring strategy that includes identification of key parameters to measure, determination of a sampling schedule and procedure, and establishment of a training protocol for proper sampling and reporting. The shipyard has the appropriate analytical equipment at the chemistry lab to perform trace-metal analysis within the lab, requiring no additional capital outlay for equipment or facilities. The necessary training and techniques should be integrated into the business practices of the Shipyard because the State of Hawaii has no commercial laboratories that can perform trace metal analysis.

Training and Information Access

This study took several samples at the Shipyard from sampling points that have copper- or zinc-containing fittings. The metals within the fittings contaminate the samples, yielding artificially high sample values, as explained for the seawater intake (or PWC firemain) in Section 12. As this study progressed, and through trial and error, alterations of sampling techniques procedures did eliminate some sources of sample contamination.

For long-term evaluation of BMP effectiveness, the Shipyard should establish “clean” sampling points (USEPA, 1996a) within the various waste streams to assist with source identification and control. Sampling points should be constructed or replaced with non-copper or zinc-containing materials such as Teflon®, PVC, or other plastics, including valves and piping materials. If metallic materials are required, stainless steel or titanium should be selected as alternatives to copper or brass.

To evaluate BMPs and meet regulatory requirements, Code 106 should work closely with the chemistry lab to require lower detection limits and appropriate analytical techniques for processed samples. Generally, the instrument and method detection limits should be below the regulatory limits. Developing this capability would benefit Code 106, allowing sampling throughout the Shipyard to evaluate the effectiveness of various BMPs and individual waste streams before mixing and associated contaminant contributions.

The Shipyard should also consider implementing BMPs that involve cross-organizational changes and would require support from senior-level Shipyard management. The Shipyard requires that an environmental brief be given to all new contractors. Included in that brief are suggested BMPs and procedures designed to reduce Shipyard pollution. This brief is a good first step, and if combined with internal enforcement capabilities, would become a very effective tool in reducing contaminant loads.

As a follow-on to this brief, all contracts at the Shipyard should include specific BMP elements and associated penalties for lack of performance, which can slowly change the attitudes regarding pollution control. In addition, all Shipyard employees and contractors should receive refresher training once a year and when significant changes are made to the management practices that affect their activities. These management actions will help establish that environmental compliance is not only a compartmental issue for Code 106 to resolve, but that contractor, management, public relations, and environmental personnel should be actively involved in BMPs and keeping the Shipyard in business.

Executive Order (E.O.) 13148, Greening the Government through Leadership in Environmental Management, requires each Federal agency, including PHNSY&IMF, to integrate environmental accountability across all missions, activities, and functions, and into day-to-day decision-making, long-term planning, and processes. The Under Secretary of Defense (Acquisition, Technology, and Logistics) issued the Department of Defense Environmental Management System (EMS) policy memorandum, recognizing the different missions among Department of Defense components and providing support to implement an EMS that best fits its mission needs. The Shipyard's EMS conforms with Naval Sea Systems Command (NAVSEA)'s Occupational Safety, Health, and Environmental (OSHE) Control Manual, Chapter 420, and the Chief of Naval Operations Environmental Management Guide.

The Shipyard is currently applying an EMS to develop, implement, maintain, review, correct, and improve environmental compliance issues. It is a structured approach that incorporates environmental considerations into day-to-day operations throughout the Command, and is designed to promote continual improvement.

The Shipyard's EMS is designed to identify, rank, and control significant environmental aspects, set metrics to judge progress, and use the ranked environmental aspects to set objectives to be used as a mission improvement program tool. Significant aspects include air emissions (particulate matter, volatile organic compounds, hazardous air pollutants) from hazardous materials usage such as painting, woodworking, abrasive blasting, and adhesive application.

Several shipyards throughout the country are applying this approach. It systematically improves environmental compliance and reduces costs. The successful implementation of this process involves senior management and employees throughout the Shipyard.

The Shipyard is developing additional environmental objectives and targets and training personnel in specific procedures to control the environmental impacts of their activities. The Shipyard has identified processes and activities that are associated with significant environmental aspects and continues to develop and implement management plans and standard operating procedures.

Constantly engaged in activities to raise the level of environmental awareness, the Shipyard is working to make program documents available on an Intranet. Management reviews are conducted on an annual basis to review and update the program.

New Technologies

The Shipyard should continue to look toward the future and ensure that all pollution pathways have been clearly defined and characterized. This commitment will streamline the development and adoption of new BMPs and technologies that will reduce or eliminate pollution at the Shipyard. For example, the Shipyard and NAVSEA are examining several companies that are manufacturing closed-loop, ultra-high-pressure paint removal systems.

These systems require less manpower, recycle and capture all wastewater, take up a small amount of dry dock floor space, require less containment and cleanup, and allow for other ship maintenance operations to occur simultaneously (and in close proximity) to ongoing paint removal operations. The cost associated with acquiring this type of system may be commensurate with other options such as extending dry dock outfalls; however, these systems have a larger benefit because the Shipyard would be removing metal contamination at the source instead of continuing to discharge contaminants.

The performance and real-world application of this technology is being carefully evaluated against the unique requirements of the Navy before they are fully adopted; however, the intent is to keep the Shipyard's P^2 efforts focused on new procedures and new technologies to maintain business and comply with regulations in a cost-effective manner.

CONCLUSION

The application of new BMPs for pollution control at the Shipyard based on a rigorous pollution pathway analysis is the most cost-effective means to meet increasingly stringent environmental regulations. As discharge regulations continue to require lower overall contaminant loading, it is incumbent upon the Shipyard to manage resources to meet these requirements. Many simple and inexpensive BMPs have already been adopted at the Shipyard, which is a good indicator to the regulatory community that the Shipyard is making a “best faith” effort to control and reduce pollution associated with its discharges.

The next steps involve capital and personnel resources and organizational changes to meet regulatory requirements. The problems facing the Shipyard are industry-wide, with multiple organizations working on mitigation strategies. The Shipyard can benefit from the experiences and successes of these other organizations by adopting successful mitigation strategies already developed and tested elsewhere.

The cost benefits are important to consider with these individual BMPs because many alternatives such as military construction projects represent much larger time and resource commitments from the Navy, with uncertain effectiveness. The Shipyard should continue to stay updated on the state-of-the-art knowledge base and associated support capabilities to keep the Navy “fit to fight” and continue as stewards of the environment.

SECTION 4

RECALCULATION OF COPPER WATER QUALITY STANDARD

INTRODUCTION

This section presents results from the Navy's recalculation effort for copper in support of site-specific WQS for Pearl Harbor.

The Recalculation Procedure followed USEPA guidance (USEPA, 1994b) to adjust the current national WQC for copper using a step-wise method that involves corrections, additions, and deletions to the national toxicity data set, rendering it more representative of species occurring at the site. The procedure addressed an outdated USEPA-recommended criterion of 2.9 µg/L total recoverable copper (USEPA, 1984a), which is used in the PHNSY&IMF current NPDES permit for its dry docks (HIDOH, 2002).

METHODS

The recalculation was performed using a more comprehensive toxicity data set that was used to develop the 1995 recommended criteria of 4.8 and 3.1 µg/L for acute and chronic exposure (USEPA, 1995a), both of which are expressed on a dissolved basis. The procedure resulted in acute and chronic criteria of 7.8 and 5.0 µg/L, respectively, which was a result of one correction, three additions, and two deletions to the 1995 data set. The procedure produced criteria that would provide the level of protection intended by USEPA (USEPA, 1985a), as well as regulatory relief to those facilities that discharge copper into Pearl Harbor.

EPA regulations direct that the Recalculation Procedure be performed first, when the Recalculation Procedure and a WER are to be used in developing a site-specific criterion (USEPA, 1994b). This rule was developed because the recalculated acute or criterion maximum concentration (CMC), and/or chronic or continuous criterion concentration (CCC), must be used in selecting the primary and secondary tests for the WER.

The primary test, for example, must have an endpoint (e.g., LC50, EC50, IC50) as close as possible, but not below the acute and/or chronic criterion to which the WER will be applied. This requirement ensures that the site-specific criterion will provide adequate protection, as less-sensitive species tend to produce lower WERs (USEPA, 1994b). The secondary test, however, can have an endpoint above or below the recalculated criterion. The site-specific CMC of 7.8 µg/L is below the USEPA species mean acute value (SMAV) of 9.63 µg/L (USEPA, 1995a) for the selected primary test species, *Mytilus galloprovincialis*. The secondary species (*Crassostrea gigas*) has an expected EC50 of 17.84 µg/L (USEPA, 1995a). Therefore, the criteria were met and the test method selection for the WER was not impacted.

A site-specific WQC adjustment for copper in Pearl Harbor, Hawaii, was derived using the USEPA's Recalculation Procedure (USEPA, 1994b; USEPA, 1997). This procedure involves corrections, additions, and deletions to the state or national toxicity data set that was used to develop WQC or WQS, resulting in a data set that is more representative of the fauna present at the site. Once the appropriate modifications were made to the data set, a new criterion was calculated using USEPA guidelines for Deriving Numerical National Water Quality Criteria for the Protection of Organisms and Their Uses (USEPA, 1985a).

The current WQC for copper in marine waters in the State of Hawaii is 2.9 µg/L, expressed as TRM. This criterion does not distinguish between acute and chronic conditions, and was established following studies performed by HIDOH in 1991. Sampling and analysis of marine and estuarine surface waters in Hawaii revealed mean concentrations below USEPA's ambient saltwater criterion for copper, which was 2.9 µg/L at the time (USEPA, 1984a). According to June Harrigan (HIDOH), the decision to adopt this concentration as its criterion was made because independent testing by HIDOH indicated that total recoverable copper concentrations in the receiving water bodies were below USEPA's nationally recommended criterion of 2.9 µg/L.

Since Hawaii's WQC for copper is based on the 1984 national data set, it might seem appropriate to use this data set for the recalculation. In 1995, however, USEPA published an Addendum (USEPA, 1995a; Appendix C) to the 1984 document, which included a number of corrections and additions to the data set. Among the changes was the conversion of data from TRM to DM. If dissolved data were not available for a particular species, a multiplication factor of 0.83 or 0.90 was used, depending on whether the reported data were based on total recoverable or nominal (unmeasured) concentrations, respectively. The 1995 Addendum also included the addition of new toxicity data that added six new genera to the data set, bringing the total number of genera represented to 26. The 1995 Addendum resulted in acute and chronic criteria for copper of 4.8 and 3.1 µg/L, respectively.

These values were derived using USEPA guidelines (USEPA, 1985a), which involved calculating a Final Acute Value (FAV) based on the number of genera in the data set and the toxicity values for the four most sensitive genera in the data set (Table 4). The resulting FAV of 10.39 µg/L was above the genus mean acute value (GMAV) for *Mytilus*; therefore, it was lowered to 9.625 µg/L to protect this commercially important species, as dictated by the guidelines (USEPA, 1985a). The acute criterion was then obtained by dividing the *Mytilus* GMAV (normally, it is the FAV) by 2, and the chronic criterion was obtained by dividing the FAV by a Final Acute-to-Chronic Ratio (FACR). The FACR of 3.127 was calculated as the geometric mean of four species mean acute-to-chronic ratios (ACRs) for *Daphnia*, *Gammarus*, *Physa*, and *Mysidoposis*.

A draft update to the 1995 Addendum was published recently (USEPA, 2003), bringing the total number of genera in the database to 44. At the beginning of this study, the 2003 document had only recently been released for public review and comment. As of August 2006, USEPA had still not responded to these comments, and had not made the document official. Because it appears that the 2003 draft will be further modified, the 1995 data set for the recalculation was considered the most appropriate on which to base the recalculation effort, as was originally proposed in this study's sampling and analysis plan.

Table 4. Four most sensitive genera in the USEPA 1995 Addendum data set.

Sensitivity Rank	Genus	Genus Mean Acute Value (µg/L)
4	*Arbacia* (Sea urchin)	21.40
3	*Mulinia* (Coot clam)	17.70
2	*Paralichthys* (Summer flounder)	11.56
1	*Mytilus* (Blue mussel)	9.625

Although not necessarily needed if minimum data requirements are met, the Recalculation guidelines (USEPA, 1994b) provide the option of submitting additional toxicity data for consideration by USEPA, which is especially important where critical (that is, endangered, threatened, or commercially or recreationally important) species are concerned. The addition of toxicity data for resident species in Pearl Harbor was based on their presence in the water body and relevancy based on USEPA guidelines (USEPA, 1985a).

Following a thorough investigation and incorporation of appropriate corrections and additions to the data set, the deletion process outlined in USEPA guidelines (USEPA, 1994b; USEPA 1997) was used to determine which species should be removed based on their absence, or absence of a surrogate species, in Pearl Harbor. Decision-making was facilitated by reference to a very comprehensive invertebrate and fish database created by the Pearl Harbor Legacy Project (PHLP) for invertebrates and fish, available through the Bishop Museum in Honolulu, Hawaii (Bishop Museum, 1998), as well as other pertinent publications and personal communications. The Recalculation Procedure led to an increase in the CMC (acute criterion) from 4.8 to 7.8 µg/L and an increase in the CCC (chronic criterion) from 3.1 to 5.0 µg/L.

RESULTS

Recalculation Corrections

Eastern Oyster (Crassostrea virginica)

The national data set's SMAV of 25.67 µg/L for this species is based on unmeasured LC50/EC50 values. As per the USEPA guidelines (USEPA, 1985a), species mean values based on measured values must be used, if available. As part of a WER study for the Navy in the Hampton Roads/ Elizabeth River Estuary, six laboratory water EC50s with a geometric mean of 29.18 µg/L dissolved copper were generated (CH2M HILL, 2000). Therefore, the dissolved value of 29.18 µg/L should be used as the SMAV for *C. virginica*, instead of 25.67 µg/L.

Recalculation Additions

Three species were added to the data set based on their reported presence in Pearl Harbor, ecological or economic significance, and the availability of relevant toxicity data that meets USEPA requirements (USEPA, 1985a). The added species are *Tripneustes gratilla* (Hawaiian collector urchin), *Pocillopora damicornis* (lace coral), and *Oreochromis mossambicus* (Mozambique tilapia). None of these species are on the endangered or threatened species list.

Hawaiian Collector Sea Urchin (Tripneustes gratilla)

According to the PHLP Database (Bishop Museum, 1998), this sea urchin species is present in Pearl Harbor. It is a very common species of the Indo-Pacific region, living in bays and lagoons on various substrates, and has a tendency to cover itself with rubble and detritus. Copper toxicity data are available for two different endpoints with this species: fertilization success and embryo-larval development. The fertilization success endpoint is currently being demonstrated as a chronic whole effluent toxicity (WET) test by USEPA for use in NPDES permits in Hawaii.

This test method is still in development, and is reportedly complicated by such factors as satisfactory egg condition, organism availability, and difficulty in attaining optimum sperm-to-egg ratios. Additionally, the potential for variability in results among test batches and obtaining false assessments of biological impacts also exists (Vazquez, 2003). More importantly, this endpoint does not qualify for use in WQC development (USEPA, 1985a) tests because tests with single-celled organisms are not considered acute tests.

Therefore, embryo-larval development data were used instead, as this endpoint is acknowledged as acceptable in the USEPA guidelines (USEPA, 1985a). A mean EC50 value of 15.66 µg/L copper was reported in 96-hour exposures (USEPA, 1996c). The coefficient of variation for the three exposures was 4.33%, suggesting low variability among the three experiments. Because the data are based on nominal concentrations, a 0.9 conversion factor (USEPA, 1995a) was used to calculate a dissolved concentration of 14.09 µg/L, which was used as the GMAV in the site-specific data set.

Lace Coral (Pocillopora damicornis)

Lace coral is a scleractinian coral that has recently been observed in multiple locations of Pearl Harbor, even at sites located well inside the Harbor (Coles, 1999; Coles, DeFelice, Eldredge, and Carlton, 1999; Coles et al., 1997; Bishop Museum, 1998). Corals, however, have not been historically observed in Pearl Harbor (Bishop Museum, 1998). Coles et al. (1997) concluded that the small to medium size of the corals found in a 1996 study suggest that conditions in Pearl Harbor have only recently become amenable to coral settlement and growth.

Coral planula larvae survival has been used to a limited extent as an experimental toxicity test endpoint. Although adult corals have been reported as more sensitive than the planula larvae, assessment of death in adults is difficult (Esquivel, 1983) and no adult coral tests exist that satisfy the USEPA guidelines for deriving WQC (USEPA, 1985a). Esquivel (1983) observed a total recoverable EC50 of 63 µg/L copper after a 96-hour static exposure to *P. damicornis* planula larvae at 27 °C.

Shorter exposures indicated less sensitivity, with 120, 115, and 90 µg/L EC50 values after 12, 24, and 48 hours of exposure, respectively. The most sensitive result (96 hours) was added to the database. Because the data appear to be based on nominal concentrations, the 0.9 correction factor (USEPA, 1995a) was used to convert the EC50 to a dissolved concentration of 56.70 µg/L.

Mozambique (Red) Tilapia (Oreochromis mossambicus)

This species has been reported to occur in Pearl Harbor in several studies dating from 1973 to 1996 (Bishop Museum, 1998; Coles et al., 1999). It is an introduced species originally from East Africa, and is of commercial importance in much of the world. Juveniles of this species were quite tolerant to copper in 96-hour exposures (Nussey, van Vuren, and du Preez, 1996). LC50 values were 2,610 and 2,780 µg/L, based on total recoverable copper, for exposures at 29 and 19 °C, respectively. The geometric mean of these values is 2,695 µg/L.

The publication indicated that metal was measured, but expressed as total recoverable metal, with an atomic absorption spectrophotometer. Therefore, for inclusion in the site-specific data set, the 0.83 conversion factor (USEPA, 1995a) was used to calculate a dissolved LC50 of 2,237 µg/L.

Recalculation Additions Considered, But Not Included

Two species for which limited toxicity data are available were considered, but deemed inappropriate for addition to the site-specific data set. These species are *Coryphaena hippurus* (common dolphinfish [Mahi Mahi]) and *Isognomon californicum* (mangrove oyster).

Mahi Mahi (Coryphaena hippurus)

Mahi mahi are widely found in semi-tropical and temperate marine waters, and have very high commercial value. These fish inhabit open waters, but do approach the coast. In 1990, D. A. Zieman evaluated eggs and yolk sac larvae as potential toxicity testing tools in 24- to 96-hour exposures.[5] Difficulty in rearing of larvae resulted in inconclusive larval test results following 96-hour exposures.

Egg survival appeared to be a better endpoint, with a mean LC50 estimate of 166 µg/L total recoverable Cu from three individual tests. Egg survival is an endpoint that is not normally used in WQC derivation (USEPA, 1985a). Furthermore, because of its pelagic nature, this species is not

[5] D. A. Zieman. 1990. “Acute Chronic Toxicity for Water Quality Management: Final Report prepared for HIDOH by OI Consultants, Waimanalo, HI.

expected to be present in Pearl Harbor and it was not reported in the species listing of the Pearl Harbor Legacy Project (PHLP) database (Bishop Museum, 1998).

Mangrove Oyster (Isognomon californicum)

The mangrove oyster is a small (up to 1½ inches) bivalve that has characteristics of oysters and mussels. It is believed to be endemic to the Hawaiian Islands, and reportedly is found abundantly in areas that receive fresh water (Ringwood, 1989). Ringwood (1992) demonstrated successful use of embryos and larvae of *I. californicum* in 48-hour toxicity exposures with copper, and reported an embryo total recoverable copper EC50 value of 7 µg/L. Although observed in other areas of South Oahu, this species was not listed in the PHLP database (Bishop Museum, 1998).

Personal observations by John Zardus (Kewalo Marine Laboratory, Honolulu, Hawaii) indicate a preference for this species to occupy exposed coastal areas. The PHLP database did report isolated occurrences of other species from the genus *Isognomon.* Coles et al. (1997) observed *Isognomon legumen*, but only at the entrance channel to Pearl Harbor, which has significantly more exposure to oceanic conditions than any of the other sites studied in the harbor. Furthermore, no copper toxicity data for *I. legumen* were found, so it could not be considered for addition to the data set.

Recalculation Deletions

Blue Mussel (Mytilus sp.)

Embryos of mussels such as *Mytilus edulis* and *M. galloprovincialis* are very sensitive to copper, and this genus is ranked as the most sensitive in the 1995 national toxicity data set (USEPA, 1995b). These species are known to occur in cold and temperate climates, and are usually found in littoral and shallow sublittoral waters, but are occasionally found in deeper waters. They live in the open ocean and in estuaries on a variety of substrata such as rock, stones, and compacted mud or sand. They are also present as fouling organisms on ships, pier pilings, and harbor walls. *M. edulis* is reported to occur in the Arctic, and continues southward to North Carolina in the western Atlantic and southern France in the eastern Atlantic, in the northern hemisphere (Bayne, 1976).

In the southern hemisphere, they are known to occur in Chile, Argentina, and the Falkland and Kergeuleun Islands (Seed, 1992). Previous reports of *M. edulis* along the Pacific coast of the United States were likely *M. galloprovincialis* (Gosling, 1992; Seed, 1992). Growth, feeding, and embryo development of *M. edulis* becomes arrested at temperatures above 25 °C, and is optimal between 10 and 20 °C (Bayne, 1976; Gonzalez and Yevich, 1976; USFWS, 1983). As temperatures in Pearl Harbor vary annually between 23 and 29 °C (Coles et al., 1999), this species is not expected to be present in Pearl Harbor.

The PHLP database (Bishop Museum, 1998) indicated two observations of the family Mytilidae on bottoms of ships in 1950. The genus and species were not identified. It is likely that these were cases of pre-existing fouling, as it is not expected that *Mytilus sp.* would survive in Hawaii because of the warm temperatures in Pearl Harbor. The lack of subsequent reporting of this family in Pearl Harbor since 1950 strengthens this assumption. Therefore, it was concluded that *Mytilus sp.* are not present at this site.

The Recalculation Procedure (USEPA, 1994b) states that a species not present at the site can be deleted from the data set if another species present at the site and in the data set is from the same class (a "circled" species). Because *Crassostrea gigas* and *C. virginica*, are present in Pearl Harbor, are in the data set, and are in the same class (Bivalvia) as *Mytilus sp.*, *Mytilus* was deleted.

Summer Flounder (Paralichthys dentatus)

According to the PHLP database (Bishop Museum, 1998), the summer flounder is an Atlantic species that is not present in Pearl Harbor. The closest related species that has been reported in Pearl Harbor is the Leopard flounder (*Bothus pantherinus*), which is in the same order, Pleuronectiformes. *B. pantherinus* is a relatively small (up to 39 cm) flounder found throughout the Indo-Pacific region. It inhabits sandy or silty sand, and muddy bottoms of inner reef flats and seaward reefs. It is not of commercial importance to the Hawaii region.

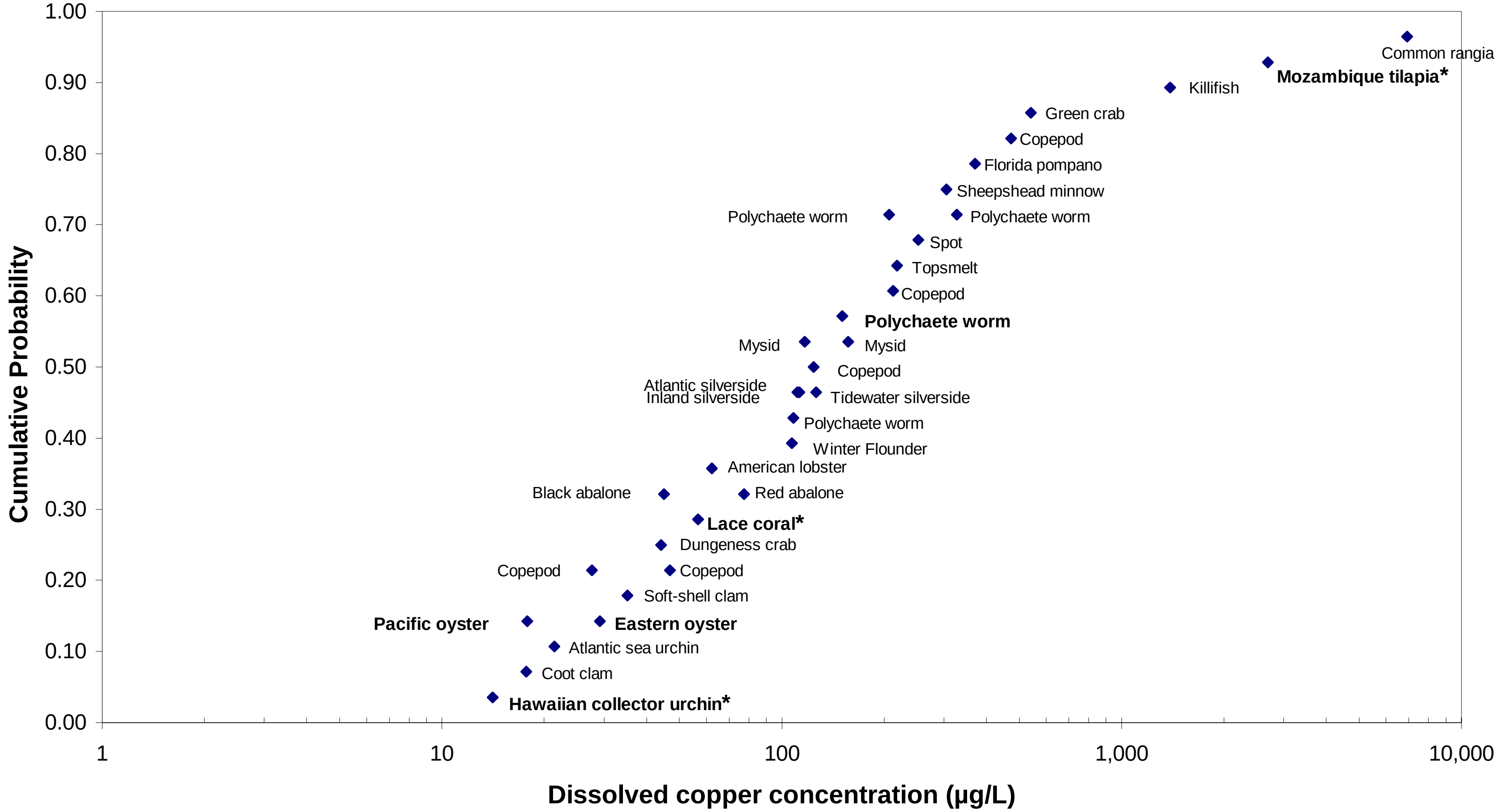
The PHLP database reported only two specimens of this species in Pearl Harbor from a single survey in 1974. In the 1974 survey, one fish was caught, and another sighted, near the entrance channel to the harbor (Evans et al., 1974). Its rare observation suggests that this species is not normally present in the Harbor. Furthermore, because another species (*Oreochromis mossambicus*) from the same class (Actinopterygii) is present in the data set and Pearl Harbor, *Paralichthys dentatus* was deleted.

If *B. pantherinus* were considered present at the site, the relatively low SMAV listed in the national data set for *P. dentatus* would be deleted under the life-stage deletion process (USEPA, 1997). The SMAV of 11.56 µg/L for *P. dentatus* is based on tests involving early cleavage of the embryo. However, *B. pantherinus* is believed to spawn only in the sea, and only the post larvae enter estuaries (Cyrus and Martin, 1991).

CONCLUSION

One correction was made to the 1995 national toxicity data set, which involved substitution of the SMAV for *C. virginica* to one based on measured copper concentrations as opposed to unmeasured concentrations. Three additions and two deletions were also made, resulting in 27 genera (Figure 9), as opposed to the 26 in the national data set (USEPA, 1995b). The adjusted copper dataset used for the recalculation is provided in Appendix D.

The four most sensitive genera in the site-specific data set are listed in Table 5. Two of the four genera are present in Pearl Harbor, while a total of five genera in the site-specific data set occur in Pearl Harbor. Using the site-specific data set, a FAV of 15.63 µg/L was calculated. From this FAV, CMC (acute) and CCC (chronic) values of 7.82 and 5.00 µg/L, respectively, were calculated per the equations provided in the USEPA’s WQC derivation document (USEPA,1985a).



Legend: Bold: Species are present in Pearl Harbor.
Bold and followed by an asterisk: Species that were added to the data set.
Non-bold: Species that were retained from the national data set.

Figure 9. Site-specific data set used for Pearl Harbor copper criterion recalculation.

Table 5. Four most sensitive genera in the Pearl Harbor data set.

Sensitivity Rank	Genus	Genus Mean Acute Value (µg/L)
4	*Crassostrea* (Eastern and Pacific oysters)	22.82
3	*Arbacia* (Sea urchin)	21.40
2	*Mulinia* (Coot clam)	17.70
1	*Tripneustes* (Collector urchin)	14.09

SECTION 5

WATER EFFECT RATIO

INTRODUCTION

A WER study was conducted using embryos of sensitive marine invertebrates as a means of deriving a site-specific WQC for copper. The objective of a WER, therefore, is to modify the State WQS (currently 2.9-µg total recoverable copper/L in the State of Hawaii) for Pearl Harbor, Hawaii, and establish new permit limits. The investigation involved extensive toxicity testing associated with four sampling events at eight different locations representing the whole harbor during March 2005 through May 2006. The WER Procedure uses standardized toxicity testing to quantify the difference in a metal's toxicity between site water and laboratory water, which results in a ratio that is subsequently multiplied by the national criterion to derive a site-specific criterion.

The USEPA promulgated the WER procedure for developing site-specific WQC and effluent limits for NPDES permits (USEPA, 1994b). Estuarine water bodies generally have higher concentrations of metal binding ligands, including particulate matter and organic carbon, than laboratory waters (e.g., synthetic or filtered, open coastal seawater). Since laboratory water is typically used for development of national WQC, resulting criteria may be overprotective because of the greater capacity of most natural water bodies to reduce a metal's bioavailability and toxicity. Because of these potential differences, adopting the national WQC at a site may result in a level of protection substantially greater than that intended by the USEPA guidelines for criteria derivation (USEPA, 1985a).

Numerous studies throughout the nation have examined applying WERs as a way to provide regulatory relief [6] (Rosen, Rivera-Duarte, Kear-Padilla, and Chadwick, 2005). In the marine environment, WER studies have generally resulted in an adjustment of the national criterion by a factor of approximately two.

For four naval bases in the Hampton Roads, Virginia, area, WER tests with a marine copepod (*Acartia tonsa*) resulted in total recoverable and dissolved WERs of 2.30 and 1.76, respectively (CH2M HILL, 1999). A New York Harbor (New York, New York) WER study resulted in a dissolved WER of 1.5, using a combination of three species, including *Mytilus edulis* as well as the sea urchin *Arbacia punctulata* (USEPA, 1994b; 1995). San Francisco Bay, California, has been the focus of several WER studies. A bay-wide total recoverable WER of 1.7 was obtained in 1991 using toxicity tests with embryos of the Pacific oyster (*Crassostrea gigas*), while a subsequent study of South San Francisco Bay that employed *M. galloprovincialis* embryos resulted in total and dissolved WERs of 3.66 and 2.77, respectively (City of San Jose, 1998). Dissolved WERs for San Diego Bay, California, were estimated at 1.54 to 1.67, while total recoverable WERs were estimated at 2.07 to 2.27 (Rosen et al., 2005).

The magnitude of the WER has been correlated to the concentration of TSS and/or DOC concentrations at some sites. The DOC concentration in particular appears to predict mussel embryo dissolved copper EC50s within a reasonable degree of precision (Arnold, 2005; Arnold, Cotsifas, and Corneillie, 2006) and is expected to play a large role in developing a saltwater Biotic Ligand Model (BLM) that may ultimately be used as an alternative to WER studies for site-specific criteria development.

[6] Gauthier et al., 1999.

To calculate a WER, extensive laboratory toxicity testing and chemical analyses associated with that testing are required. Side-by-side toxicity tests are conducted to assess the differences in the toxicity of a metal added to laboratory water (e.g., that used to develop national WQC, on which NPDES permit limits are based) and site water (e.g., surface water from Pearl Harbor). The median lethal or effect concentration (LC50 or EC50) in the site water is divided by the LC50 or EC50 in the laboratory water to derive the WER. Since multiple sites and sampling events are typically involved, the geometric mean of individual WERs is used to calculate a final WER for the site. The USEPA has proposed two methods for conducting WER studies (USEPA, 1994b), one using simulated conditions and the other using actual conditions.

This study used Method 2 (actual field conditions), following discussions with the HIDOH that resulted in the decision to develop a WER that could be applied to the all of Pearl Harbor, rather than only to conditions associated with the U.S. Naval Shipyard facility. Preliminary sampling to determine the potential benefit of conducting a WER study was conducted at three surface-water sites adjacent to the Shipyard in Pearl Harbor in October 2002 and March 2003. The preliminary sampling events resulted in dissolved WERs of 1.44 and 1.17, respectively (geomean of the three sampling locations), confirming that conditions at the site were overprotective. To encompass all of Pearl Harbor, an additional five sites were included in the official WER study, bringing the total number of ambient seawater sites to eight.

Historically, WER studies have used two species: the primary species, which is used in a minimum of three sampling events, and a secondary species, which is tested alongside the primary species for one event, as a confirmatory measure (USEPA, 1994b). For this study, the Mediterranean mussel (*Mytilus galloprovincialis*) was selected as the primary species, as it is one of two recommended species for WER studies (USEPA, 1994b) and has a copper toxicity endpoint (embryo-larval development EC50 ~ 9.6 µg Cu/L) that is near the CMC (4.8 µg Cu/L [USEPA, 1995a]).

The current national WQC for copper is based solely on toxicity data for this species and endpoint (USEPA, 1995a), making it particularly relevant. The secondary species chosen was the Pacific oyster (*Crassostrea gigas*), which is present in Pearl Harbor, is similar in sensitivity to the mussel, yet is taxonomically different, as required by the WER guidance. The oyster could not be used as the primary species because of its limited spawning season. Although not required, embryo-larval development tests with the purple sea urchin (*Strongylocentrotus purpuratus*), another USEPA-recommended species, were also included for one event, bringing the number of species evaluated in this study to three.

The results of this study indicate that adoption of a site-specific criterion for Pearl Harbor could provide regulatory relief to local dischargers while still providing the level of protection intended by WQC guidelines (USEPA, 1985a). The consistently low dissolved copper concentrations (overall mean: 0.62 ±0.25 µg/L) measured in the harbor during this study suggest that current copper loading does not result in levels unsafe to the biota, which was corroborated by an absence of ambient toxicity from all samples and for all species examined in this study.

METHODS

The WER study was designed and conducted in accordance with appropriate USEPA guidance documents for the development of site-specific criteria (USEPA, 1994b, 2001), as specified by HIDOH in the Shipyard's current dry dock NPDES permit (HIDOH, 2002). Toxicity testing associated with the study followed standardized procedures commonly used for evaluating toxicity of effluents and receiving waters to early life stages of bivalves (mussels, oysters) and echinoderms (sea urchins) (ASTM, 1999a; 1999b; USEPA, 1995b).

Sample Collection and Handling

Site water was collected from the water surface (depth of approximately 1 meter) using clean techniques (USEPA, 1996b) during four scheduled events: 15–18 March 2005, 18–20 October2005, 23–27 January 2006, and 15–19 May 2006. Table 6 and Figure 10 show all eight sample locations and their location in Pearl Harbor. To capture any variability in Shipyard operations as well as temporal variability, samples were spaced over several months. During the January 2006 sampling event, over 1.7 inches of rainfall was recorded throughout the week, representing a rainy season set of samples. Before sampling, new pre-cleaned 1-liter high-density polyethylene (HDPE) bottles were thoroughly rinsed with 18 MΩ/cm of water.

Samples were shipped on ice overnight to SSC San Diego. Upon arrival, samples were immediately evaluated for condition and water quality parameters, including arrival temperature (Appendix E). If necessary, samples were stored at approximately 4° C upon arrival in the laboratory, but test set-up generally commenced immediately on arrival. Holding time of samples for WER studies is limited to 96 hours following sample collection (USEPA, 2001). Additional samples were collected for copper analysis (see Copper Measurements subsection), as well as TSS and DOC.

Table 6. Sample location names, abbreviations, and positions in Pearl Harbor, Hawaii, for WER study.

Sample ID	Abbreviated Sample ID	Coordinates (Degrees, Minutes, Seconds)	
		Latitude	Longitude
North	N	21 21 46.6	157 56 52.5
South	S	21 20 10.7	157 58 14.6
Central	C	21 21 13.3	157 58 06.6
West Loch	WL	21 21 55.55	158 00 30.38
East Loch	EL	21 22 31.19	157 57 20.84
Middle Loch	ML	21 22 31.32	157 58 53.38
North Middle Channel	NMC	21 22 03.08	157 58 19.98
West Loch Channel	WLC	21 20 59.49	157 59 13.09

Site and Laboratory Water Preparation

Analyses of site water under the microscope indicated the presence of live zooplankton and phytoplankton for most samples, but predation on mussel, sea urchin, or oyster embryos was not expected. Therefore, to best preserve sample integrity, samples were tested without any pre-sieving. Site water salinity was generally 33 to 34‰, within range of the test protocols and that tolerated by the test species, and close to ambient lab water salinity (~34‰). Therefore, no salinity adjustment was made to site water samples. One site water sample (ML from Event 3) did have a relatively low salinity (26‰), and was therefore paired with a lower salinity laboratory water. The laboratory water in this case was diluted with 18-MΩ/cm water.

Two types of laboratory water were used in this study: (1) coastal seawater collected from the filtration tanks adjacent to the research pier at Scripps Institution of Oceanography in La Jolla, California (which will be referred to as "SIO"), and (2) coastal seawater from the Marine Pollution Studies Laboratory (MPSL) at Granite Canyon (GC) in Monterey, California (which will be referred to as "GC"). Both waters were filtered to 0.45 µm, and are typically clean (e.g., low copper concentration) and low in suspended solids and DOC, which are characteristics of water used for WQC development (USEPA, 1985).

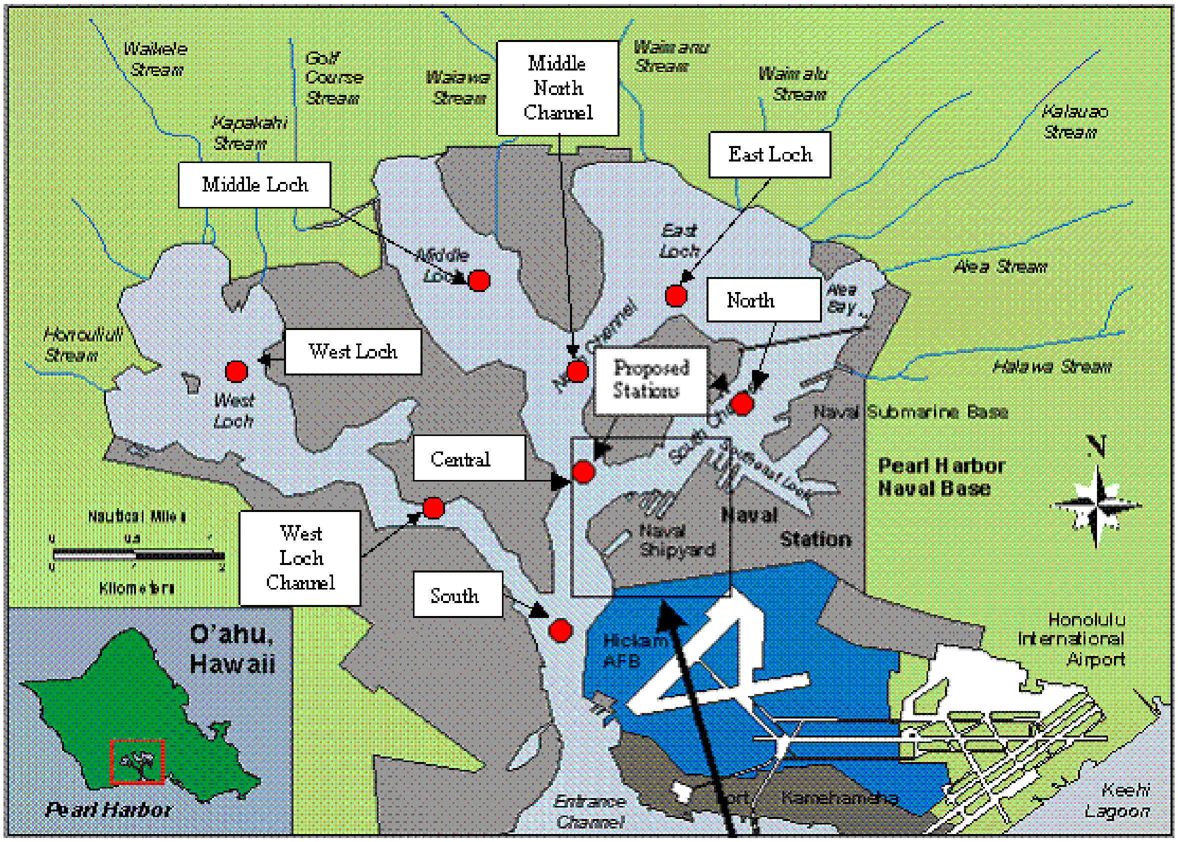


Figure 10. Sampling locations for water studies at PHNSY&IMF.

Because the testing laboratory typically uses SIO laboratory dilution water for assessing laboratory and test-batch performance (e.g., reference toxicity tests), copper EC50s from this water were compared to the lab's control charts as one means of assessing data quality. GC seawater has been used in toxicity test method development, WQC development, and previous WER studies (e.g., City of San Jose, 1998; USEPA, 1995b; USEPA, 2003). Therefore, its usefulness as laboratory water for WER studies has been previously demonstrated.

Test Species

Toxicity testing was conducted with embryos from a total of three species, one primary and two secondary. The primary species was used for all four sampling events, and was used for final WER calculations, while the secondary species served to validate the WER calculations derived by the primary species. According to the WER guidance (USEPA, 1994b), there is no reason to use species that occur at the site. Appendix F provides a detailed discussion of the species selection approach used in this study. The primary tests involved embryo-larval development of the Mediterranean mussel (*Mytilus galloprovincialis*).

This species and life stage is relevant because embryogenesis of *Mytilus sp.* is impacted by copper at very low concentrations (e.g., < 10 µg/L; USEPA, 1995b; USEPA, 2003), and the toxicity end-point selected for WER studies should be as close as possible to the criterion that is being adjusted (USEPA, 1994b). The 48-hour embryo-larval development endpoint for *Mytilus sp.* is the driver of the current saltwater ambient WQC, which are 4.8 and 3.1 µg dissolved Cu/L, for acute and chronic criteria, respectively (USEPA, 1995a).

The previous criterion of 2.9 µg/L was also driven by *Mytilus sp.* (USEPA, 1984a). In addition, *Mytilus sp.* is specifically recommended by the USEPA for use in saltwater WER studies (USEPA, 1994b). Development of the saltwater Biotic Ligand Model (BLM) for copper has also focused specifically on this species and toxicity test endpoint. *M. galloprovincialis* used in this study were obtained from Carlsbad Aquafarm, Carlsbad, California.

The purple sea urchin (*Strongylocentrotus purpuratus*) is the recommended secondary species for WER studies (USEPA, 1994b) and was tested alongside the mussels in Event 2. The embryo-larval development endpoint is nearly as sensitive as that of the mussel (USEPA, 2003), suggesting it should result in similar WERs.

A number of Hawaiian sea urchin species (e.g., *Heterocentrotus mammillatus, Echinometra mathaei, Tripneustes gratilla*) are present in or near Pearl Harbor, suggesting that purple sea urchins may be a good surrogate for less well-studied local species. Purple sea urchins were field-collected by Marinus Scientific in Long Beach, California.

Embryos of the Pacific oyster (*Crassostrea gigas*) were tested concurrently with the mussels during Event 4. Pacific oysters are present in Pearl Harbor (Bishop Museum, 1998) and their sensitivity to copper is similar to the mussels (USEPA, 1995b; USEPA, 2003). Their limited spawning season restricted their use as a secondary species only. Conditioned oysters were provided by the Molluscan Broodstock Program at Oregon State University's Hatfield Marine Science Center in Newport, Oregon.

Toxicity Tests

Toxicity tests were conducted following American Society of Testing and Materials (ASTM) and USEPA guidance for whole effluent toxicity (ASTM, 1999a; ASTM, 1999b; USEPA, 1995b) and for determining WERs (USEPA, 1994b). Site and laboratory water samples were spiked with as many as eight nominal copper concentrations, ranging from 2.9 to 35 µg/L, using a dilution factor of 0.7. Copper stock solutions were made from copper sulfate and confirmed by STGFAA spectroscopy before use. The same stock solution was used for laboratory waters, site waters, and associated reference toxicant tests. Test concentrations were prepared separately in acid-cleaned and seawater-leached 125-mL Erlenmeyer flasks. From each flask, 10 mL were distributed to each of five new seawater-conditioned, glass 20-mL scintillation vials for the bioassay. A sixth replicate for at least one test concentration per sample was also included and used for quantification of total recoverable and dissolved copper by STGFAA at the end of the test to account for any change in copper concentration compared to initial concentrations. An equilibration period of 3 to 5 hours was allowed following copper additions prior to the addition of embryos.

Mussels were induced to spawn by thermal shock (raising the temperature by about 10 °C from ambient), oysters were strip-spawned by prying open the shells and removing eggs and sperm, and sea urchins were induced to spawn by injection of 0.5 mL of 0.5 M KCl into the peristomal membrane. Within 4 hours of fertilization, approximately 200 embryos at or beyond the two-cell stage were added to each test vial. Vials were then incubated at the appropriate temperature for the designated exposure time under a 16-hour light: 8-hour dark photoperiod. Water quality (pH, temperature, dissolved oxygen, salinity) was recorded daily for all tests. Tables 7 and 8 provide a summary of the targeted test conditions and test acceptability criteria. Water quality measurements are summarized in Appendix G.

After 48 hours, normally developing mussels and oyster embryos have achieved the prodissoconch I stage, characterized by a straight-hinged, D-shaped larval shell. After 72 to 96 hours, normal sea urchin larvae are referred to as a pluteus, and are characterized by a pyramidal shape with four well-developed skeletal arms. Both types of larvae are shown in Figure 11.

Two different endpoints were used to assess larval development: percent normal development and percent normal survival, which are defined as follows. Percent normal development refers to the number of normal straight-hinged, D-shaped larvae relative to the total number of larvae (normal and abnormal) counted in a vial at the conclusion of the test. It does not consider any embryos that may have perished during the exposure.

The normal survival endpoint measures the percentage of normally developed D-shaped larvae observed at the end of the test relative to the initial number of embryos added to the test vial, as determined from initial density vials preserved shortly after test initiation. Normal survival, therefore, is a more comprehensive endpoint, as it considers both survival and normal larval development success. The normal survival endpoint was ultimately used for EC50 calculations for this reason. Larvae were evaluated with the aid of an inverted compound microscope at 40 to 60x magnification.

Data Analysis

Toxicity metrics (EC50s) were calculated from normal survival calculations with ToxCalc™ version 5.0, using several point estimation techniques. The Maximum Likelihood Probit method was the preferred method. In several instances, however, the assumptions for Probit analysis were not met, so the Trimmed Spearman Karber (TSK) method was used in its place. All EC50 values were also calculated using the linear interpolation method.

If the Probit method cannot be used for some samples, the WER guidance requires using the linear interpolation method (USEPA, 1994b). Therefore, EC50 and WERs shown in this report are a result of the linear interpolation method. For comparison purposes, WERs were also derived using the Probit and TSK point estimation techniques, illustrating negligible differences in the final WER outcome. EC50 and WER values were calculated from nominal, total recoverable, and dissolved copper measurements for the multiple exposure concentrations for each test.

WERs for each site water sample were calculated by dividing the site water EC50 by the associated lab water EC50. No observable effect concentrations (NOEC) and lowest observable effect concentrations (LOEC) were obtained from hypothesis testing following arc-sine square-root transformations of the toxicity data and verification of normal distribution of data and homogeneity of variances using Shapiro–Wilkes and Bartlett’s tests, respectively.

Table 7. Test parameters for bivalve embryo-larval development tests with *Mytilus galloprovincialis* (Mediterranean mussel) and *Crassostrea gigas* (Pacific oyster) as described by the method guidance and as targeted in this study.

Parameter/Criterion	ASTM 1999a	USEPA 1995b	This Study
1. Test salinity (ppt)	18-32 ± 1	30 ± 2	34 ppt ± 10%
2. Test Temperature (ºC)	16 ± 1 (mussels) 20 ± 1 (oysters)	15 or 18 ± 1 (mussels) 20 ± 1 (oysters)	15 or 18 ± 1 (mussels) 20 ± 1 (oysters)
3. Light quality/intensity	Ambient lab levels	Ambient lab levels	Ambient lab levels
4. Photoperiod (hours)	16 h light: 8 h dark	16 h light: 8 h dark	16 h light: 8 h dark
5. Test chamber size (mL)	10-30	10-30	20
6. Test solution volume (mL)	10-30	10	10
7. Embryos/mL	15-30	15-30	15-30
8. Number of replicates/concentration	3	4	5
9. Dilution water	uncontaminated seawater	1 µm filtered natural seawater	0.45 µm filtered natural seawater
10. Test duration (hours)	48	48-54	48
11. Test Endpoint	survival & normal shell dev.	survival & normal shell dev.	survival & normal shell dev.
12. Test Acceptability Criteria	1) ≥ 70% of introduced embryos must result in live larvae with completely developed shells in the controls 2) ≥ 70% normal shell dev in surviving controls	1) control survival must be ≥ 50% (mussels), ≥ 70% (oysters) 2) ≥ 90% normal shell dev. in surviving controls 3) % MSD < 25%	1) ≥ 70% of introduced embryos must result in live larvae with completely developed shells in the controls 2) ≥ 70% normal shell dev in surviving controls
13. Broodstock geographical area reported and consistent	yes	yes	yes
14. Initiation of test after fertilization	within 4 h	within 4 h	within 4 h
15. Sample holding time (h)		< 36	< 96[1]
16. Lab water TSS/TOC requirements	< 5 mg/L		< 5 mg/L
17. D.O., salinity, temp., pH measured	yes	yes	yes
18. D.O. level/% saturation	60-100% sat	> 4.0 mg/L	> 4.0 mg/L

[1]As required by USEPA 2001 (Streamlined Water-Effect Ratio Procedure for Discharges of Copper)

Table 8. Test parameters for echinoderm embryo-larval development tests with *Strongylocentrotus purpuratus* (purple sea urchin) as described by the method guidance and as targeted in this study.

Parameter/Criterion	ASTM 1999b	USEPA 1995b	This Study
1. Test salinity (ppt)	27-36 ± 1	34 ± 2	34 ppt ± 10%
2. Test Temperature (ºC)	14 ± 1	15 ± 1	15 ± 1
3. Light quality/intensity	Ambient lab levels	Ambient lab levels	Ambient lab levels
4. Photoperiod (hours)	16 h light: 8 h dark	16 h light: 8 h dark	16 h light: 8 h dark
5. Test chamber size (mL)	10-30	10-30	20
6. Test solution volume (mL)	10	10	10
7. Embryos/mL	15-30	15-30	15-30
8. Number of replicates/concentration	3	4	5
9. Dilution water	uncontaminated seawater	1 µm filtered natural seawater	0.45 µm filtered natural seawater
10. Test duration (hours)	72-96	70-74	96
11. Test Endpoint	survival & normal larval dev.	normal development	survival & normal larval dev.
12. Test Acceptability Criteria	1) ≥ 70% of introduced embryos must result in live normally developed pluteus larvae in the controls	1) ≥ 80% normal development in controls 2) % MSD < 25%	1) ≥ 70% of introduced embryos must result in live normally developed pluteus larvae in the controls
13. Broodstock geographical area reported and consistent	yes	yes	yes
14. Initiation of test after fertilization	within 4 h	within 4 h	within 4 h
15. Sample holding time (h)		< 36	< 96[1]
16. Lab water TSS/TOC requirements	< 5 mg/L		< 5 mg/L
17. D.O., salinity, temp., pH measured	yes	yes	yes
18. D.O. level/% saturation	60-100% sat	> 4.0 mg/L	> 4.0 mg/L

[1]As required by USEPA 2001 (Streamlined Water-Effect Ratio Procedure for Discharges of Copper)

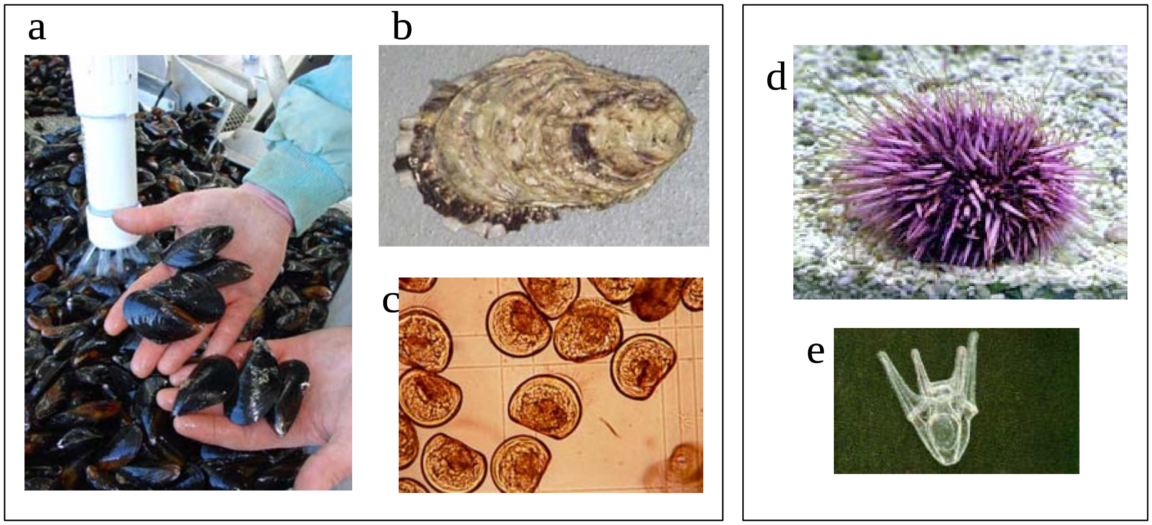


Figure 11. Test organisms used in this study, including (a) mussels (*Mytilus galloprovincialis*), (b) Pacific oyster (*Crassostrea gigas*), (c) bivalve D-shaped larvae (120 µm), (d) purple sea urchin (*Strongylocentrotus purpuratus*), and (e) sea urchin pluteus larva (200 µm).

One-way analysis of variance (ANOVA) or t-tests were used to determine if WERs were significantly different among the sampling events (over time), and, where possible, among the individual stations across events (over space) at a significance level of 0.05. The potential for ambient toxicity was assessed by comparing development success in the controls for each test (site water with no added copper) with test acceptability criteria for control performance. Control development in the site waters was also compared with that in the lab water, using one-way ANOVA ($\alpha = 0.05$). Linear regression analysis quantified relationships between EC50 and TSS and DOC.

Quality Assurance

The toxicity testing was conducted and evaluated using quality assurance (QA) procedures in accordance with the SSC San Diego Bioassay Laboratory QA Plan, which is based on applicable protocols and guidance documents. These procedures encompass all aspects of testing, including the sampling, handling, condition, receipt, and proper storage of samples and test organisms, as well as the appropriate calibration and maintenance of instruments and equipment. All data generated by the laboratory were evaluated for completeness and accuracy. Appropriate laboratory controls were conducted with each test, and were required to meet specific test acceptability criteria. For all test types, ≥70% normal survival in the controls is required for the test to be acceptable.

In addition, reference toxicant tests were conducted with each test as a measure of the laboratory's performance and test-batch sensitivity. Reference toxicant EC50 values were required to be within two standard deviations of the running mean. Minor excursions of targeted water quality objectives (Tables 7 and 8) during the tests were evaluated for their impact on the tests on a case-by-case basis. Excursions in temperature and salinity of less than 0.5 ºC or 0.5 psu, respectively, were considered inconsequential.

Copper Measurements

Copper spiked Solutions

During toxicity test set-up, 20 mL of each test solution were also dispensed into an acid-cleaned HDPE scintillation vial. Within 24 hours, 10 mL of each of these samples was filtered using clean techniques (see below) using acid-cleaned, 0.45-µm, all-polycarbonate membrane filters into another pre-cleaned HDPE scintillation vial.

The remaining unfiltered sample and the filtered samples were then immediately acidified with Q-HNO_3 until analysis by STGFAA. Filtered and unfiltered samples provided dissolved and total recoverable copper concentrations, respectively, to support the toxicity assessment and WER calculations by allowing precise EC50 determination for each form of the metal. A sixth toxicity test replicate from one test concentration was handled in the same manner at the end of the exposure to quantify any change in concentration between initial and final conditions.

Ambient Copper

Concurrent with the toxicity test samples, additional ambient water samples were collected to measure total recoverable and dissolved copper in the unspiked solutions. These samples underwent a preconcentration step, as discussed below.

Total Recoverable and Dissolved Copper Measurements

Sampling protocols followed for ambient waters collected are those of USEPA Method 1669, USEPA's Trace Metals Sampling Technique (USEPA, 1996b). These protocols include using plastic acid-cleaned bottles and sampling equipment, and "clean-hands/dirty-hands" techniques. The bottles used for collection of ambient samples are made of polyethylene and were filled with 18-MΩ/cm water, acidified with 200-µL Q-HNO_3, and double-bagged in a class-100 working area.

Collection of ambient waters is done by continuous pumping of surface water with a peristaltic pump equipped with a Teflon® diaphragm pump-head and Teflon® tubing. This system is similar to that indicated in Appendix E.2.4 of the Metals Translator Guidance (USEPA, 1996a); but, the Teflon® tubing is lowered to the desired depth and the pump is always onboard.

Unfiltered samples were collected at each station and collection of a sample was preceded by a triple rinse with sample water, then overfilling the bottle, rinsing the cap, and discarding the excess sample to leave the water level to the neck of the bottle. Preservation, handling, and analysis of the samples were done in class-100 trace metal clean working areas. For the preservation, 2 mL of Q-HNO_3 per liter of sample were added to decrease the pH to less than 2.

QA included bottle blanks, field blanks, and field duplicates. Equipment blanks were not used, as field blanks do not indicate contamination. Ambient samples were treated by liquid/liquid preconcentration with dithiocarbamates following Bruland, Coale, and Mart (1985). This treatment is performed to decrease the amount of salts in the sample, which interfere in the measurement, and to increase the concentration of copper for better accuracy and precision in the measurement.

Copper concentrations were measured by STGFAA spectroscopy with Zeeman background correction. The SRM CASS4 (coastal seawater) from the National Research Council of Canada was used to quantify the recovery of the liquid/liquid preconcentration, blanks of 1N Q-HNO_3, and the SRM 1643d (trace metals in water) of the National Bureau of Standards were used to evaluate the limit of detection, precision, and accuracy of the STGFAA analysis.

Chemistry duplicates of one exposure concentration (targeted near the expected EC50) from each test were used to confirm that copper did not change substantially during the toxicity test exposure period, as recommended (USEPA, 1994b). The selected nominal test concentrations were 12 and 17.2 µg/L for mussel/oyster and sea urchin tests, respectively. One vial was filtered and acidified at test initiation, while the second was filtered and acidified at the end of the exposure, and the percent difference was calculated. These duplicate samples were measured by STGFAA as described above and 50% metal loss was used as the acceptability criterion.

WER studies include the collection of ambient waters, the set-up of batches of these ambient waters spiked with different levels of copper concentration, the addition of larva, and the evaluation of the toxic concentration to those larva. Therefore, while the initial concentration in the samples is at ambient level, the copper concentration in the spiked aliquots includes a fairly large range from less than 1 up to 50 µg/L. Ambient waters impose a Quality Assurance/Quality Control (QA/QC) for sampling and analysis of those waters. In this case, ambient waters were first preconcentrated and the copper concentration was measured by STGFAA. In the case of the spiked aliquots, they were diluted with 1N Q-HNO_3 and then directly injected into a STGFAA for measurement. Therefore, QA/QC for each of these steps is required.

QA/QC for sampling includes using field and bottle blanks. The average concentration for the field blanks was 0.070 ±0.076 µg/L (n = 4), and one bottle blank was measured with a copper concentration of 0.011 µg/L. The average field blank copper concentration is 13% (range 5 to 53%) of the average dissolved concentration, and 10% (range 4 to 39%) of the average total copper concentration measured in ambient samples.

The analytical QA/QC for the liquid/liquid preconcentration step included using SRM CASS4 and duplicate extractions. An average recovery of 93.9 ±2.3 % (n = 4) was measured for the certified copper concentration of 0.592 ±0.055 µg/L for CASS4, which indicates that the copper concentrations measured on the preconcentrated samples are, on average, 93.9% of the actual value. Replicate extractions were used to evaluate the precision of the extraction, and an average Relative Standard Deviation (RSD) of 3.7 ±3.6 % (n = 5) was calculated for them. That is, the copper concentration measured in preconcentrated samples had an average precision within ±3.7%.

The QA/QC for the analysis by STGFAA of the preconcentrated samples included using SRM 1643d, 1N Q-HNO_3 blanks, and spiked samples. The method of standard additions was used with STGFAA. The procedure for each batch of samples analyzed included the following:

- Rod blank, which is the copper concentration in the graphite tube and platform themselves.
- Standard addition with at least three standards in the first sample to be analyzed, with a correlation coefficient (r) of 0.999 or better.
- Measurement on the other samples in the batch.
    - ♦ Including a SRM 1643d and a 1N Q-HNO_3 Blank every five samples.
    - ♦ Including analysis of a sample and of the same sample spiked with standard.
- Standard addition with at least three standards in the same first sample, with a correlation coefficient (r) of 0.999 or better.
- Calculation of the slope of both standard additions, and calculation of the slope for each sample assuming a linear change in slope.
- Using the calculated slope and dilution to calculate the measured copper concentration for each sample.

For the STGFAA analysis of the preconcentrated samples, an average recovery of 94.7 ±4.2 % (n = 44) was calculated for SRM 1643d, which is within the ±15% (85 to 115%) recovery required for QA/QC, and indicates that the measured concentrations, on average, are 94.7% of the actual value. The average concentration for the 1N Q-HNO_3 blanks was 0.045 ±0.063 µg/L (n = 61), with a Method Detection Limit of 0.188 µg/L calculated as three standard deviations of the blanks. Concentrations measured after liquid/liquid preconcentration do include a preconcentration factor after the STGFAA analysis for actual calculation, and most of the preconcentrated samples, except for the blanks, require a dilution to bring the copper concentration into the linear range of the STGFAA. Recovery for spiked samples had an average of 104.9 ±5.1% (n = 6), also within the range of 15% required by QA/QC.

The QA/QC for STGFAA analysis of 1N Q-HNO_3-diluted WER samples also included using SRM 1643d, 1N Q-HNO_3 blanks, and spiked samples. An average recovery of 104.0 ±6.5 % (n = 40) was calculated for the analysis of SRM 1643d,.which is within the ±15% (85 to 115%) recovery required for QA/QC and indicates that the measured concentrations, in average, are 104.0% of the actual value. The average concentration for the 1N Q-HNO_3 blanks was 0.027 ±0.043 µg/L (n = 56), with a Method Detection Limit of 0.129 µg/L calculated as three standard deviations of the blanks. Recovery for spiked samples had an average of 108.4 ±8.1 % (n = 5), also within the range of 15% required by QA/QC.

RESULTS

Test Acceptability

Four WER study events were conducted during 15 March 2005 through 19 May 2006, which resulted in 71 copper toxicity tests (48 site water tests and 23 lab water tests). Final WERs were calculated separately, using data from the first three events and data for all four events together. As with the first three events, the fourth sampling event resulted in successful toxicity tests based on data quality objectives (see Tables 27 and 28 in section 6) and acceptable total recoverable copper measurements.

Dissolved copper measurements for the spiked test solutions, however, were deemed invalid because of very abnormal values obtained that did not correspond with observed effects (e.g., dissolved values were substantially higher than total recoverable values and no trend was apparent with increasing nominal concentration, even though a dose response was observed). Investigation into the problem revealed that a problem occurred during the filtration of these samples (filtering equipment contamination). Therefore, dissolved EC50s were not calculated for the fourth event, and dissolved WERs associated with Event 4 are expressed as estimates based on mean dissolved total ratios determined from the first three events.

Toxicity test conditions and acceptability criteria used in the study are shown in Tables 27 and 28. Water quality measurements (pH, temperature, dissolved oxygen, salinity) were within target ranges for >99% of all measurements, with only a few minor exceedances in temperature (<0.5 °C) and salinity (<0.5 psu), and no exceedances in pH or dissolved oxygen. The copper reference toxicant tests conducted with SIO water always resulted in nominal EC50 values that fell within the laboratory's control chart limits.

Finally, control performance exceeded the minimum 70% normal survival criterion for all but one of the total of 11 test batches. Control performance for the first test set-up (17 May 2006) with Pacific oysters achieved normal survival of 56 and 57% in SIO and GC lab waters, respectively. These data were flagged but not discarded due to several factors, including normal dose response curves and resulting copper EC50s from copper additions. Data associated with that event were presented with and without the affected tests.

Appendix H shows comparisons of initial and final copper measurements made for one test concentration associated with each test. For mussels and oysters, the mean recovery of copper at the end of the exposures for the 12-µg/L nominal concentration was 84 ±19% for total recoverable and dissolved measurements. Similarly, the mean recovery for sea urchins for the 17.2-µg/L nominal concentration was 89 ±5 and 85 ±4%, for total recoverable and dissolved measurements, respectively. Two total recoverable measurements (40.1 and 49.2%) were slightly below the targeted 50% objective, while no dissolved measurements fell below 50%.

Ambient Toxicity

No ambient toxicity was observed in any of the site water samples throughout the study. Summaries of control (no copper added) larval development success are provided in Figure 12 and Table 9. Appendix I provides all control data for all test types. Larval development in the unspiked (ambient) laboratory and site water samples was evaluated using two endpoints: percent normal development and percent normal survival (see Methods section for definitions). Percent normal survival always exceeded the 70% threshold for control acceptability (ASTM, 1999a, 1999b) for all test species, except for one of the oyster test batches (17 May 2006 test setup, Event 4).

For the four events, mussel test normal survival averaged 85 and 84% (range = 74 to 91%) for SIO and GC laboratory waters, respectively, and 85% (range = 74 to 96%) for all Pearl Harbor sites combined (Figure 12, Table 9). Site water normal survival was never significantly lower than normal survival in the corresponding laboratory waters ($p>0.05$).

Similarly, the percent normal development endpoint was also high in all mussel laboratory and site water samples, averaging 91 (range = 82 to 98%) and 90% (range = 79 to 98%) for SIO and GC laboratory waters, respectively, and 91% (range = 81 to 98%) for all Pearl Harbor sites combined (Figure 12, Table 9). Once again, the site water controls were never significantly lower than lab water controls.

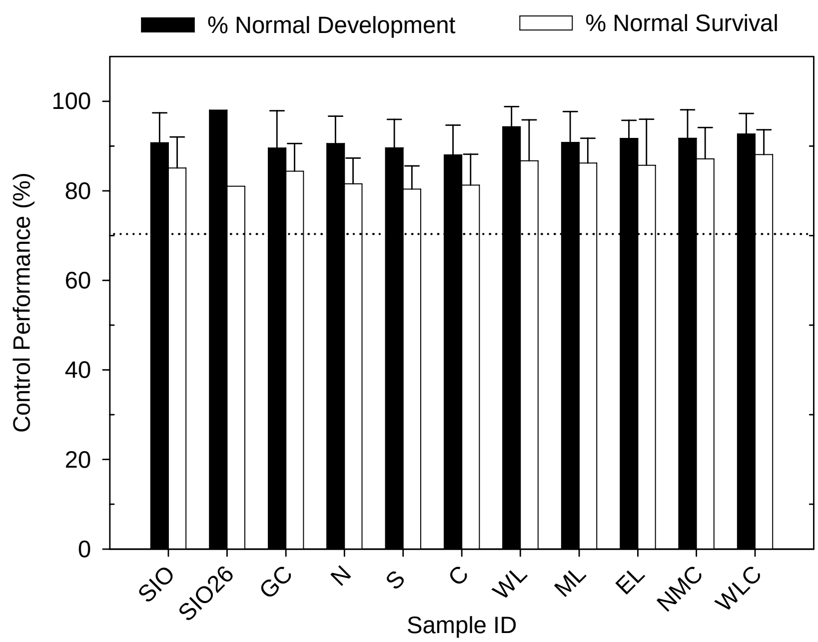


Figure 12. Mean (±1 standard deviation) control performance for mussel (*Mytilus galloprovincialis*) embryos exposed to laboratory waters (SIO, SIO26, GC) and ambient seawater (N, S, C, WL, ML, EL, NMC, WLC) for four sampling events in Pearl Harbor, Hawaii. Control was expressed as percentage of normal development and percentage of normal survival. The dashed line represents minimum test acceptability (70%) requirements for controls, and error bars indicate one standard deviation. n = 7 for laboratory waters, and four for all site water samples, except SIO26 (n = 1).

Table 9. Mean (±1 standard deviation [SD]) control performance for mussel (*Mytilus galloprovincialis*) embryos exposed to laboratory waters (Lab) and ambient seawater (Site) for four sampling events in Pearl Harbor, Hawaii.

Water Type	Sample ID	*n*	% Normal Mean	% Normal SD	% Normal Survival Mean	% Normal Survival SD
Lab	SIO	7	91	6.6	85	6.9
Lab	SIO26	1	98	0.0	81	0.0
Lab	GC	7	90	8.3	84	6.2
Site	N	4	91	6.1	82	5.8
Site	S	4	90	6.3	80	5.2
Site	C	4	88	6.6	81	6.9
Site	WL	4	94	4.5	87	9.1
Site	ML	4	91	6.9	86	5.5
Site	EL	4	92	4.0	86	10.3
Site	NMC	4	92	6.4	87	7.0
Site	WLC	4	93	4.6	88	5.5
Site	All Sites	**32**	**91**	**5.3**	**85**	**6.8**

Control normal survival for the secondary species also indicated no ambient toxicity (Appendix I), with all site water samples meeting or exceeding the laboratory control performance. Although one of the test batches with oysters (Event 4) indicated unacceptable normal survival in the laboratory waters (<70% normal survival), the percentage of normal development was not negatively impacted for any lab or site water sample.

Copper Toxicity–Primary Species

When copper was added to lab and site waters, a dose response was observed in all cases. Median effects concentrations (EC50) and associated 95% confidence limits (CL), no observable effects concentrations (NOEC), and lowest observable effects concentrations (LOEC) values are summarized in Tables 10 through 13. Appendix J lists concentrations from each test. Nominal values represent the calculated concentrations based on dilution of the stock solution, while total recoverable and dissolved values are based on measured copper results (Appendix K).

Dissolved EC50 values in the site water were always higher than corresponding GC lab water, except for one sample (North [N]) in Event 2, in which the values were equivalent (Table 11). For the first three events, dissolved EC50 geometric means were 6.66 (range = 4.60 to 8.13), 7.73 (range = 5.4 to 9.83), and 12.67 µg/L (range = 5.46 to 15.69) for GC, SIO, and all site waters, respectively, based on data from the first three events. The first three-event total recoverable EC50s for site water were above the corresponding GC lab water in all cases.

Total recoverable EC50 geometric means were 8.53 (range = 4.88 to 12.29), 10.41 (range = 7.11 to 14.70), and 16.84 µg/L (range = 7.20 to 26.12), for GC lab water, SIO lab water, and all site waters respectively. Total recoverable EC50 geometric means of the two test batches for the fourth event were similar to the first three events at 9.86 (range = 9.29 to 10.47), 11.55 (range = 11.10-12.07), and 15.89 (range = 11.45-19.58) µg/L.

Site water 95% CL associated with total recoverable EC50s fell within those of the GC lab water at a rate of 9% (3 of 32 samples), suggesting that the differences between site and GC lab waters were statistically significant 91% of the time. The rate of overlap was 12.5% (3 of 24 samples) for dissolved EC50s.

Copper Toxicity–Secondary Species

Toxicity metrics from the secondary species are shown in Tables 14 and 15. The purple sea urchin and the Pacific oyster were less sensitive, based on EC50 values, than the mussel to copper in concurrent confirmatory testing associated with Events 2 and 4, respectively. For sea urchins, dissolved GC lab water EC50 values averaged 12.54 µg/L, compared to 5.21 µg/L for the mussel, a difference of a factor of 2.4.

Similarly, average dissolved site water EC50 values between the two species differed by a factor of 2.6, averaging 6.81 µg/L for the mussels and 17.81 µg/L for the sea urchins. For Event 4, nominal GC lab EC50 values averaged 6.81 and 9.45 µg/L for mussels and oysters, respectively, indicating a difference in sensitivity by a factor of 1.4. This relationship was upheld when comparing the average nominal site water EC50 values of 10.32 and 14.47 µg/L for mussels and oysters, respectively, a factor difference of 1.4.

The sea urchin testing also resulted in an overlap incidence of 12.5% (1 of 8 samples) for dissolved CLs, but no incidences of overlap for total recoverable CLs. No overlap (0 of 8 samples) occurred between site water and GC lab water for oyster 95% CLs.

WATER EFFECT RATIOS

Table 16 shows nominal, total recoverable, and dissolved WERs. Final WERs were calculated using data from the first three events only and all four events, with the fourth-event dissolved WER estimated from previous dissolved:total ratios because of the lack of dissolved copper measurements for that event. A total of 24 individual WERs (eight from each event) were used for the three-event calculation, and 32 individual WERs for the four-event calculation.

Table 10. Laboratory toxicity test results with mussel (*Mytilus galloprovincialis*) embryos from Sampling Event 1. Median effects concentrations (EC50) and associated 95% confidence limits (CL), no observable effects concentrations (NOEC), and lowest observable effects concentrations (LOEC) are from additions of copper to either site or lab waters.

Test Initiation Date	Water Type	Sample ID	Nominal (µg/L)				Total Recoverable (µg/L)				Dissolved (µg/L)			
			NOEC	LOEC	EC50	95% CL	NOEC	LOEC	EC50	95% CL	NOEC	LOEC	EC50	95% CL
16-Mar-05	Lab	SIO 1	4.1	5.9	9.80	4.1-5.9	10.1	12.3	14.70	14.5-14.8	7.8	7.2	9.60	9.2-9.9
16-Mar-05	Lab	GC 1	5.9	8.4	9.73	5.9-8.4	7.6	11.7	12.29	11.9-12.6	4.0	7.8	8.13	7.9-8.3
16-Mar-05	Site	N	8.4	12	13.65	8.4-12.0	10.6	13.9	16.47	14.1-17.7	9.0	9.6	10.36	9.7-10.7
16-Mar-05	Site	S	8.4	12	11.73	8.4-12.0	12.2	13.3	13.23	12.8-14.8	7.0	10.0	9.80	8.6-11.2
16-Mar-05	Site	C	8.4	12	10.51	8.4-12.0	11.1	13.4	12.54	12.3-12.9	8.8	11.0	10.10	9.8-10.4
17-Mar-05	Lab	SIO 2	8.4	12	10.04	8.4-12.0	13.7	15.4	14.47	14.3-14.6	8.6	11.3	9.83	9.6-10.0
17-Mar-05	Lab	GC 2	8.4	12	10.29	8.4-12.0	11.4	13.0	12.24	12.1-12.3	7.3	8.8	8.09	8.0-8.2
17-Mar-05	Site	WL	12	17.2	17.26	12.0-17.2	13.9	17.0	17.07	15.8-19.9	7.5	11.5	11.52	10.0-12.4
17-Mar-05	Site	ML	12	17.2	15.17	14.4-16.5	15.1	17.8	16.75	16.4-17.4	7.4	10.5	9.29	8.8-10.0
17-Mar-05	Site	EL	12	17.2	15.50	12.0-17.2	14.3	25.2	21.65	20.2-23.4	7.4	12.4	10.77	10.0-11.5
17-Mar-05	Site	NMC	8.4	12	14.12	8.4-12.0	10.8	14.2	16.72	15.6-17.6	6.3	8.3	9.22	8.8-9.6
17-Mar-05	Site	WLC	12	17.2	14.32	12.0-17.2	12.6	18.4	15.18	14.9-15.4	8.8	11.6	10.04	9.9-10.2

Table 11. Laboratory toxicity test results with mussel (*Mytilus galloprovincialis*) embryos from Sampling Event 2. EC50 and associated 95% CL, NOEC, and LOEC are from additions of copper to either site or lab waters.

Test Initiation Date	Water Type	Sample ID	Nominal (µg/L)				Total Recoverable (µg/L)				Dissolved (µg/L)			
			NOEC	LOEC	EC50	95% CL	NOEC	LOEC	EC50	95% CL	NOEC	LOEC	EC50	95% CL
19-Oct-05	Lab	SIO 1	<2.9	2.9	4.45	4.0-4.7	<5.6	5.6	7.11	6.8-7.3	<4.3	4.3	5.40	5.3-5.5
19-Oct-05	Lab	GC 1	2.9	4.1	4.83	4.5-5.3	2.8	5.2	6.87	6.3-7.6	4	6	5.82	5.8-6.0
19-Oct-05	Site	N	4.1	5.9	5.90	5.2-6.9	5.4	7.2	7.20	6.4-8.9	5	5.6	5.60	5.4-6.5
19-Oct-05	Site	S	4.1	5.9	7.13	6.8-7.5	5.1	6.7	8.82	8.2-9.4	4.4	5.9	6.15	6.1-6.2
19-Oct-05	Site	C	4.1	5.9	6.71	6.2-7.1	6.4	6.9	8.27	7.3-8.8	4.7	5.3	5.89	5.5-6.1
21-Oct-05	Lab	SIO 2	2.9	4.1	5.68	5.2-6.3	5.6	8.5	7.43	6.9-7.9	4.7	5.8	5.92	5.9-6.0
21-Oct-05	Lab	GC 2	<2.9	2.9	4.11	3.6-4.9	<3.3	3.3	4.88	4.2-5.6	<3.5	3.5	4.60	4.2-4.7
21-Oct-05	Site	WL	8.4	12	13.22	10.9-14.7	10.9	13.3	15.24	12.0-17.9	7.5	8.2	9.21	7.5-10.5
21-Oct-05	Site	ML	4.1	5.9	7.04	6.3-7.7	6.3	8.0	9.51	8.5-10.4	2.5	4	5.46	4.4-6.2
21-Oct-05	Site	EL	4.1	5.9	6.57	6.1-7.0	4.6	9.6	10.14	9.7-10.4	4	5.6	5.92	5.6-6.1
21-Oct-05	Site	NMC	2.9	4.1	6.14	5.3-6.5	3.5	5.4	7.80	6.6-8.6	3.4	4.8	6.72	6.1-7.4
21-Oct-05	Site	WLC	5.9	8.4	10.49	10.1-10.8	7.1	10.7	12.22	12.0-12.5	3.8	9.6	9.58	9.6-9.6

Table 12. Laboratory toxicity test results with mussel (*Mytilus galloprovincialis*) embryos from Sampling Event 3. EC50 and associated 95% CL, NOEC, and LOEC are from additions of copper to either site or lab waters.

Test Initiation Date	Water Type	Sample ID	Nominal (µg/L)				Total Recoverable (µg/L)				Dissolved (µg/L)			
			NOEC	LOEC	EC50	95% CL	NOEC	LOEC	EC50	95% CL	NOEC	LOEC	EC50	95% CL
26-Jan-06	Lab	SIO	4.1	5.9	6.71	6.0-7.1	7.1	10	10.87	10.1-11.3	5.2	8.9	9.16	8.9-9.3
26-Jan-06	Lab	SIO 26	5.9	8.4	7.53	7.1-7.8	10	11.1	10.72	10.6-10.8	8.3	8.5	8.43	8.4-8.4
26-Jan-06	Lab	GC	5.9	8.4	7.95	7.5-8.4	5.8	9.6	8.97	8.3-9.6	3.3	7.8	7.05	6.3-8.0
26-Jan-06	Site	N	8.4	12	13.13	10.8-14.5	11.4	17.2	19.31	15.1-21.9	8.3	12	12.44	11.1-12.9
26-Jan-06	Site	S	8.4	12	11.13	10.3-12.7	10.7	17	15.49	13.8-18.0	7.3	11.6	10.57	9.5-12.3
26-Jan-06	Site	C	12	17.2	14.17	13.9-14.4	16.9	23.6	19.68	19.1-20.1	9.5	19.3	13.57	12.7-14.4
26-Jan-06	Site	WL	17.2	24	20.33	19.9-20.7	24.7	26.3	25.44	25.3-25.5	13.6	14.6	14.06	14.0-14.1
26-Jan-06	Site	ML	17.2	24	21.07	20.4-21.5	23	24.9	24.06	23.9-24.2	14.8	16.4	15.69	15.5-15.8
26-Jan-06	Site	EL	8.4	12	13.50	12.4-14.2	10.4	17.4	19.19	18.2-20.1	8.2	11.2	12.36	11.4-12.9
26-Jan-06	Site	NMC	12	17.2	14.11	13.6-14.5	9.8	12.5	16.42	15.5-17.3	7.6	10.6	12.28	11.9-12.6
26-Jan-06	Site	WLC	17.2	24	20.42	20.0-20.6	25.6	26.7	26.12	26.1-26.2	11	14	12.43	12.3-12.5

Table 13. Laboratory toxicity test results with mussel (*Mytilus galloprovincialis*) embryos from Sampling Event 4. EC50 and associated 95% CL, NOEC, and LOEC are from additions of copper to either site or lab waters.

Test Initiation Date	Water Type	Sample ID	Nominal (µg/L)				Total Recoverable (µg/L)			
			NOEC	LOEC	EC50	95% CL	NOEC	LOEC	EC50	95% CL
17-May-06	Lab	SIO 1	2.9	4.1	5.1	4.8-5.3	8.3	9.4	11.10	10.5-11.5
17-May-06	Lab	GC 1	4.1	5.9	6.7	6.4-6.9	9.3	9.9	10.47	10.3-10.6
17-May-06	Site	N	5.9	8.4	8.0	7.8-8.2	11.2	15.3	14.64	14.3-15.0
17-May-06	Site	S	8.4	12	11.0	10.6-11.3	17.4	19.6	18.99	18.8-19.2
17-May-06	Site	C	5.9	8.4	9.7	9.3-10.2	11.1	14.8	15.65	15.4-15.9
17-May-06	Site	EL	8.4	12	9.9	8.1-10.7	15.4	19.4	17.01	15.2-18.0
18-May-06	Lab	SIO 2	2.9	4.1	5.0	4.7-5.1	<11.6	11.6	12.03	11.9-12.1
18-May-06	Lab	GC 2	4.1	5.9	6.9	6.8-7.0	7.2	7.9	9.29	9.0-9.5
18-May-06	Site	WL	12	17.2	14.8	14.2-15.2	16.1	21.3	18.84	18.3-19.2
18-May-06	Site	ML	5.9	8.4	10.1	9.9-10.3	9.8	10.4	13.02	12.6-13.3
18-May-06	Site	NMC	5.9	8.4	8.2	7.7-8.9	9.1	11.6	11.45	10.9-12.1
18-May-06	Site	WLC	8.4	12	14.2	13.9-14.6	12.6	17.2	19.58	19.1-20.0

Table 14. Laboratory toxicity test results with sea urchin (*Strongylocentrotus purpuratus*) embryos from Sampling Event 2. EC50 and associated 95% CL, NOEC, and LOEC are from additions of copper to either site or lab waters.

Test Initiation Date	Water Type	Sample ID	Nominal (µg/L)				Total Recoverable (µg/L)				Dissolved (µg/L)			
			NOEC	LOEC	EC50	95% CL	NOEC	LOEC	EC50	95% CL	NOEC	LOEC	EC50	95% CL
19-Oct-05	Lab	SIO 1	12	17.2	14.90	14.3-15.6	19.2	21.5	20.48	20.2-20.8	13.2	14.8	14.09	13.9-14.3
19-Oct-05	Lab	GC 1	12	17.2	15.06	14.2-15.5	12	20	16.67	15.3-17.6	10.8	16.5	14.13	13.2-14.7
19-Oct-05	Site	N	8.4	12	19.04	17.1-20.0	11.5	12.3	23.94	23.1-24.5	7.9	10.8	16.44	15.0-17.4
19-Oct-05	Site	S	17.2	24	20.94	16.7-22.4	20.7	26.2	23.73	21.1-25.0	12.9	18.3	15.87	12.5-17.0
19-Oct-05	Site	C	17.2	24	21.31	20.6-21.9	20.4	27.4	24.63	23.9-25.2	13.6	18.2	16.38	15.9-16.9
21-Oct-05	Lab	SIO 2	8.4	12	12.93	10.8-14.9	13.1	14.5	15.78	13.5-18.6	10	11.5	12.55	10.6-14.4
21-Oct-05	Lab	GC 2	<5.9	5.9	12.53	11.2-13.9	10.5	12.4	13.08	11.8-14.7	7.5	10.4	10.94	9.9-12.1
21-Oct-05	Site	WL	12	17.2	30.37	28.6-31.6	13.3	21.2	30.86	29.9-31.7	8.2	12.3	18.78	18.1-19.3
21-Oct-05	Site	ML	17.2	24	21.54	19.7-24.7	21	27.1	24.96	23.1-27.6	13.2	18.5	16.64	15.0-19.0
21-Oct-05	Site	EL	17.2	24	22.47	20.5-26.0	20.6	26.3	25.02	23.6-28.2	14.5	19.1	18.07	16.6-20.6
21-Oct-05	Site	NMC	<5.9	5.9	21.58	20.7-22.4	11.5	13.8	25.20	24.4-25.8	9.4	10.6	18.01	17.4-18.6
21-Oct-05	Site	WLC	12	17.2	27.26	25.5-28.4	13.3	20	28.70	27.6-29.5	9.6	12.8	18.87	18.3-19.5

Table 15. Laboratory toxicity test results with Pacific oyster (*Crassostrea gigas*) embryos from Sampling Event 4. EC50 and associated 95% CL, NOEC, and LOEC are from additions of copper to either site or laboratory (lab) waters.

Test Initiation Date	Water Type	Sample ID	Nominal (µg/L)				Total Recoverable (µg/L)			
			NOEC	LOEC	EC50	95% CL	NOEC	LOEC	EC50	95% CL
17-May-06	Lab	SIO 1	4.1	5.9	6.73	6.3-7.1	9.4	12.6	13.03	12.8-13.2
17-May-06	Lab	GC 1	5.9	8.4	7.77	7.0-8.4	9.9	11.6	11.17	10.8-11.5
17-May-06	Site	N	4.1	5.9	10.40	8.1-11.5	10.7	11.2	16.31	15.4-17.0
17-May-06	Site	S	8.4	12	13.91	12.9-14.4	17.4	19.6	22.32	20.6-23.1
17-May-06	Site	C	8.4	12	13.32	11.6-14.1	14.8	17.1	19.24	16.1-20.6
17-May-06	Site	EL	8.4	12	12.44	11.1-13.5	15.4	19.4	19.89	18.5-21.4
18-May-06	Lab	SIO 2	4.1	5.9	9.33	8.0-10.1	11.6	12.5	13.90	12.3-14.9
18-May-06	Lab	GC 2	8.4	12	11.14	10.6-11.5	10.9	14.9	13.95	13.4-14.4
18-May-06	Site	WL	12	17.2	19.33	18.0-20.2	16.1	21.3	23.71	22.1-25.0
18-May-06	Site	ML	8.4	12	15.42	15.0-15.8	10.4	15.8	20.86	20.1-21.5
18-May-06	Site	NMC	8.4	12	14.20	13.5-14.7	15.7	22.1	18.39	17.4-19.0
18-May-06	Site	WLC	12	17.2	20.04	19.4-20.6	17.2	22.7	26.79	26.0-27.5

Table 16. Nominal, total recoverable, and dissolved WERs determined from toxicity tests with mussel (*Mytlius galloprovincialis*) embryos over time (four sampling events) and space (eight sampling locations) in Pearl Harbor, Hawaii. Final WERs are the geometric mean of all individual WERs. Italicized values associated with dissolved data for Event 4 are estimates only.

Sampling Event #	Sample ID	Nominal	Total Recoverable	Dissolved
1	N	1.40	1.34	1.27
1	S	1.21	1.08	1.21
1	C	1.08	1.02	1.24
1	WL	1.68	1.39	1.42
1	ML	1.47	1.37	1.15
1	EL	1.51	1.77	1.33
1	NMC	1.37	1.37	1.14
1	WLC	1.39	1.24	1.24
1	Geometric Mean	1.38	1.31	1.25
2	N	1.22	1.05	1.00
2	S	1.48	1.28	1.10
2	C	1.39	1.20	1.05
2	WL	3.22	3.12	2.00
2	ML	1.71	1.95	1.19
2	EL	1.60	2.08	1.29
2	NMC	1.49	1.60	1.46
2	WLC	2.55	2.50	2.08
2	Geometric Mean	1.74	1.73	1.35
3	N	1.65	2.15	1.68
3	S	1.40	1.73	1.42
3	C	1.78	2.19	1.83
3	WL	2.56	2.84	1.89
3	ML	2.80	2.25	1.86
3	EL	1.70	2.14	1.67
3	NMC	1.78	1.83	1.65
3	WLC	2.57	2.91	1.67
3	Geometric Mean	1.97	2.22	1.70
4	N	1.36	1.40	*1.18*
4	S	1.86	1.81	*1.53*
4	C	1.65	1.49	*1.26*
4	WL	2.50	2.03	*1.71*
4	ML	1.71	1.40	*1.18*
4	EL	1.67	1.63	*1.37*
4	NMC	1.39	1.24	*1.05*
4	WLC	2.40	2.11	*1.78*
4	Geometric Mean	1.78	1.61	1.36
Final WER (Events 1-3)		**1.68**	**1.71**	**1.42**
Final WER (Events 1-4)		**1.70**	**1.69**	***1.40***

Based on all three events, no statistical differences were observed among the sample locations, with p-values of 0.543 and 0.302 for dissolved and total recoverable WERs, respectively (ANOVA, $\alpha = 0.05$). Similarly, p-values of 0.166 and 0.116 for dissolved and total recoverable WERs for all four events, respectively, indicated no statistical differences among locations.

EC50 values used for the determination of the WERs were first calculated using the Probit maximum-likelihood regression. However, some data sets violated the assumptions required for the Probit method; therefore, linear interpolation was used for EC50 determination instead, as recommended by the USEPA Guidance (USEPA, 1994b). For comparison, final WERs using EC50s derived with a combination of Probit and TSK methods differed by less than 2% from those calculated using linear interpolation (Table 17).

Table 17. Final WERs based on determination of mussel (*Mytilus galloprovincialis*) toxicity test EC50 values determined with either linear interpolation or a combination of the Probit and TSK.

Point Estimate Method	Final WER					
	Events 1 to 3 only			Events 1 to 4		
	Nominal	Total	Dissolved	Nominal	Total	Dissolved
Linear Interpolation	1.68	1.71	1.42	1.70	1.69	1.40
Probit/TSK	1.60	1.73	1.44	1.58	1.69	1.42

Tables 18 and 19 and Figures 13 and 14 summarize WER spatial variability. Although mean-site WERs ranged from 1.36 to 2.45 on a total recoverable basis, and 1.24 to 1.77 on a dissolved basis, differences were not statistically significant. Lowest WERs were associated with stations in the main channel (e.g., North [N], South [S], and Central [C] stations), while the highest WERs were always associated with West Loch (WL) and West Loch Channel (WLC). Variability among WERs was lower when data were expressed as dissolved, with percent coefficient of variations (%CV) averaging 21 to 22% and 31 to 34% for dissolved and total recoverable WERs, respectively (Tables 18 and 19).

Among the four events, geometric means of WERs varied by 71 and 37% between lowest and highest for total recoverable and dissolved WERs, respectively (Table 20). The mean WERs (arithmetic mean) ranked from lowest to highest in the order Event 1 < Event 4 < Event 2 < Event 3, based on both total recoverable and dissolved measurements (Table 20, Figure 15). A significant difference (ANOVA, $p<0.05$, Tukey's test) was determined between Events 1 and 3 (Figure 15), but no statistical differences were determined for any other grouping. Figures 16 and 17 summarize the WER data spatially.

Table 18. Based on Events 1 through 3, the mean, SD, %CV, and rank (lowest to highest) of nominal, total recoverable, and dissolved copper WERs determined from toxicity tests with mussel (*Mytlius galloprovincialis*) embryos, as organized by sample location in Pearl Harbor, Hawaii.

Sample ID	*n*	Nominal				Total Recoverable				Dissolved			
		Mean	SD	CV (%)	Rank	Mean	SD	CV (%)	Rank	Mean	SD	CV (%)	Rank
N	3	1.42	0.22	15.2	3	1.51	0.57	37.7	3	1.32	0.34	26.0	2
S	3	1.36	0.14	10.2	1	1.36	0.33	24.4	1	1.24	0.16	13.1	1
C	3	1.42	0.35	24.8	2	1.47	0.63	42.9	2	1.37	0.41	29.6	3
WL	3	2.49	0.77	31.1	8	2.45	0.93	37.9	8	1.77	0.31	17.4	8
ML	3	1.99	0.71	35.6	6	1.86	0.45	24.1	5	1.40	0.40	28.5	4
EL	3	1.60	0.10	5.9	5	2.00	0.20	9.9	6	1.43	0.21	14.6	6
NMC	3	1.55	0.21	13.6	4	1.60	0.23	14.4	4	1.42	0.26	18.2	5
WLC	3	2.17	0.68	31.1	7	2.22	0.87	39.3	7	1.66	0.42	25.3	7
Arith. Mean	24	1.75	0.56	32.0	-	1.81	0.61	33.9	-	1.45	0.32	22.0	-
Geo. Mean	24	1.68	-	-	-	1.71	-	-	-	1.42	-	-	-

Table 19. Based on Events 1 through 4, the mean, SD, %CV, and rank (lowest to highest) of nominal, total recoverable, and dissolved copper WERs determined from toxicity tests with mussel (*Mytlius galloprovincialis*) embryos, as organized by sample location in Pearl Harbor, Hawaii.

Sample ID	*n*	Nominal				Total Recoverable				Dissolved			
		Mean	SD	CV (%)	Rank	Mean	SD	CV (%)	Rank	Mean	SD	CV (%)	Rank
N	4	1.41	0.18	12.7	1	1.48	0.47	31.6	1	1.28	0.29	22.5	1
S	4	1.49	0.27	18.4	3	1.48	0.35	23.9	3	1.31	0.20	14.8	2
C	4	1.48	0.31	21.0	2	1.48	0.51	34.9	2	1.34	0.34	25.0	3
WL	4	2.49	0.63	25.3	8	2.34	0.79	33.6	8	1.75	0.25	14.4	8
ML	4	1.92	0.60	31.0	6	1.74	0.43	24.7	5	1.35	0.34	25.5	5
EL	4	1.62	0.09	5.3	5	1.90	0.25	12.9	6	1.41	0.17	12.2	6
NMC	4	1.51	0.19	12.6	4	1.51	0.26	17.2	4	1.32	0.28	21.2	4
WLC	4	2.23	0.56	25.3	7	2.19	0.71	32.5	7	1.69	0.35	20.5	7
Arith. Mean	32	1.77	0.52	29.7	-	1.77	0.55	31.4	-	1.43	0.30	21.2	-
Geo. Mean	32	1.70	-	-	-	1.69	-	-	-	1.40	-	-	-

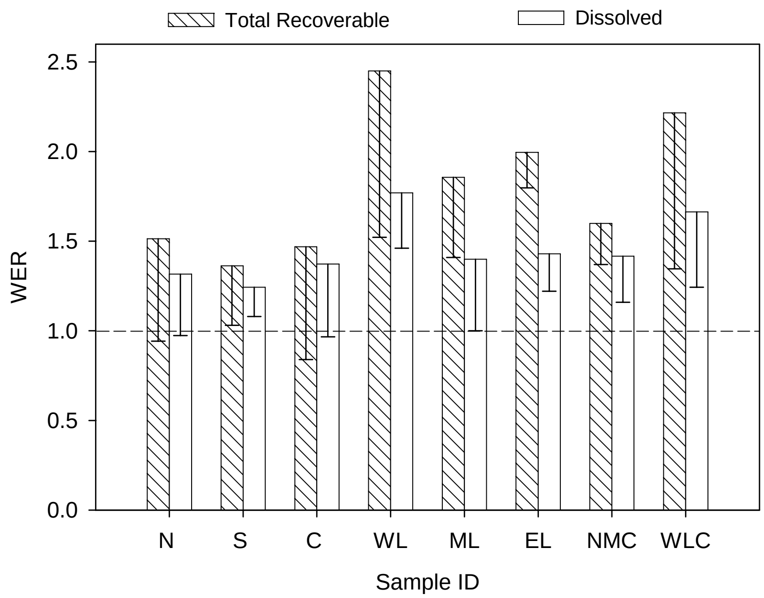


Figure 13. Mean (±1 SD) total recoverable and dissolved copper WERs from toxicity tests conducted with mussel (*Mytilus galloprovincialis*) embryos for Events 1 through 3 at eight sampling locations in Pearl Harbor, Hawaii. There was no significant difference among any of the sampling locations.

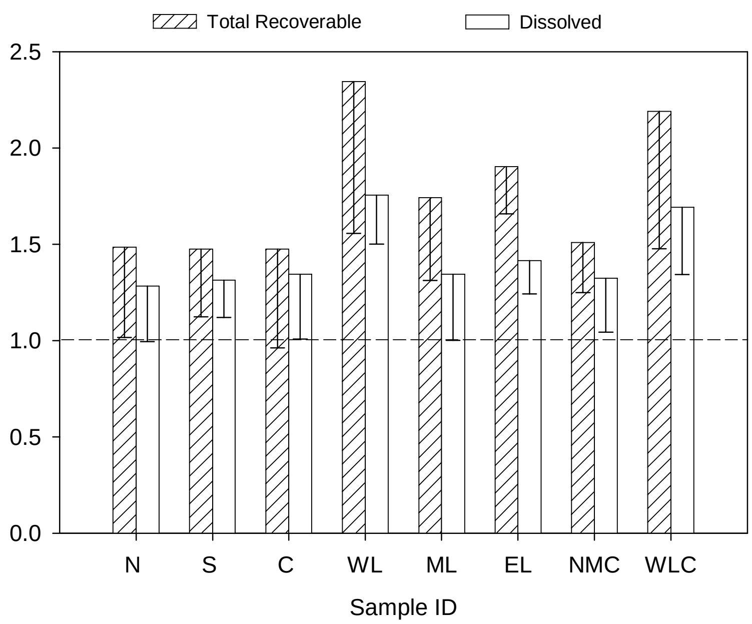


Figure 14. Mean (±1 SD) total recoverable and dissolved copper WERs from toxicity tests conducted with mussel (*Mytilus galloprovincialis*) embryos for Events 1 through 4 at eight sampling locations in Pearl Harbor, Hawaii. There was no significant difference among any of the sampling locations.

Table 20. Means, SD, %CV, and ranks (from lowest to highest, by arithmetic mean) of copper WERs for eight sampling locations in Pearl Harbor, Hawaii, from toxicity tests with mussel (*Mytilus galloprovincialis*) embryos by sampling event number. Italicized data associated with dissolved measurements for Event 4 calculations are estimates only.

	Nominal				
Event #	Geo. Mean	Arith. Mean	SD	CV%	Rank
1	1.38	1.39	0.18	13.2	1
2	1.74	1.83	0.69	37.6	3
3	1.97	2.03	0.69	33.9	4
4	1.78	1.82	0.43	23.4	2
Overall (1-3)	1.68	1.75	0.56	32.0	-
Overall (1-4)	1.70	1.77	0.52	29.7	-

	Total Recoverable				
Event #	Geo. Mean	Arith. Mean	SD	CV%	Rank
1	1.31	1.32	0.23	17.3	1
2	1.73	1.85	0.71	38.5	3
3	2.22	2.26	0.42	18.8	4
4	1.61	1.64	0.32	19.2	2
Overall (1-3)	1.71	1.81	0.61	33.9	-
Overall (1-4)	1.69	1.76	0.55	31.0	-

	Dissolved				
Event #	Geo. Mean	Arith. Mean	SD	CV%	Rank
1	1.25	1.25	0.09	7.4	1
2	1.35	1.40	0.42	30.3	3
3	1.70	1.71	0.15	8.9	4
4	*1.36*	*1.38*	*0.27*	*19.2*	*2*
Overall (1-3)	1.42	1.45	0.32	22.0	-
Overall (1-4)	*1.40*	*1.43*	*0.30*	*21.0*	-

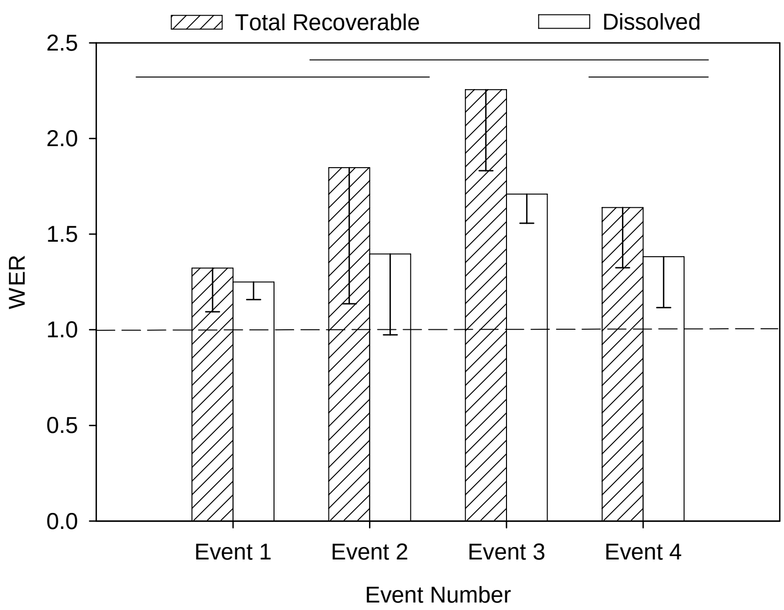


Figure 15. Mean (±1 SD) total recoverable and dissolved copper WERs from toxicity tests conducted with mussel (*Mytilus galloprovincialis*) embryos at eight sampling locations in Pearl Harbor, Hawaii, for each of four sampling events. Overlapping lines above the bars indicate a significant difference between Events 1 and 3 only.

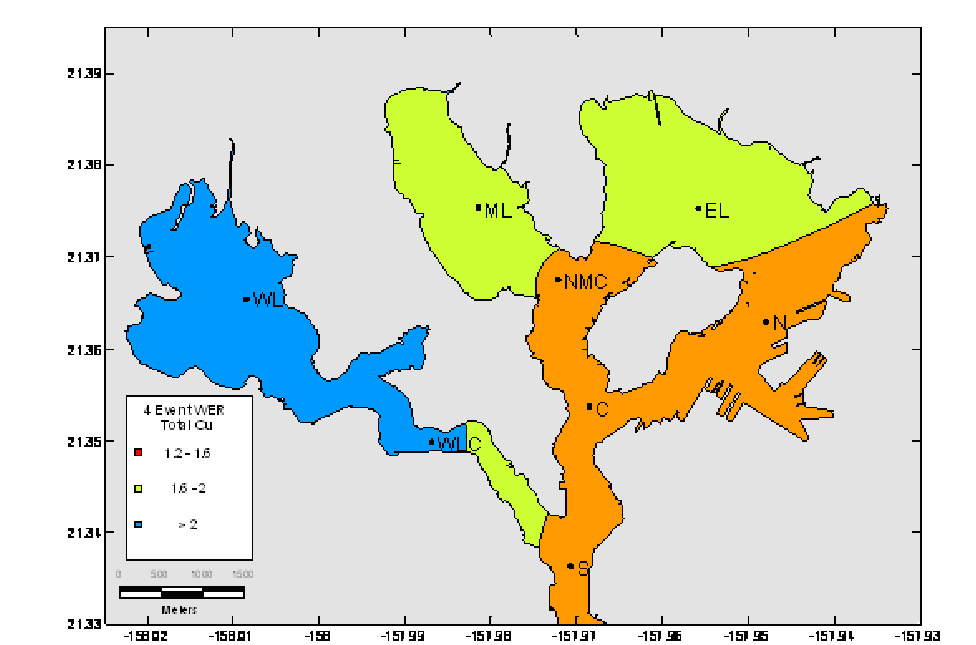


Figure 16. Spatial plot of mean total recoverable WERs determined for eight sampling locations from four sampling events in Pearl Harbor with mussel (*Mytilus galloprovincialis*) embryo toxicity tests.

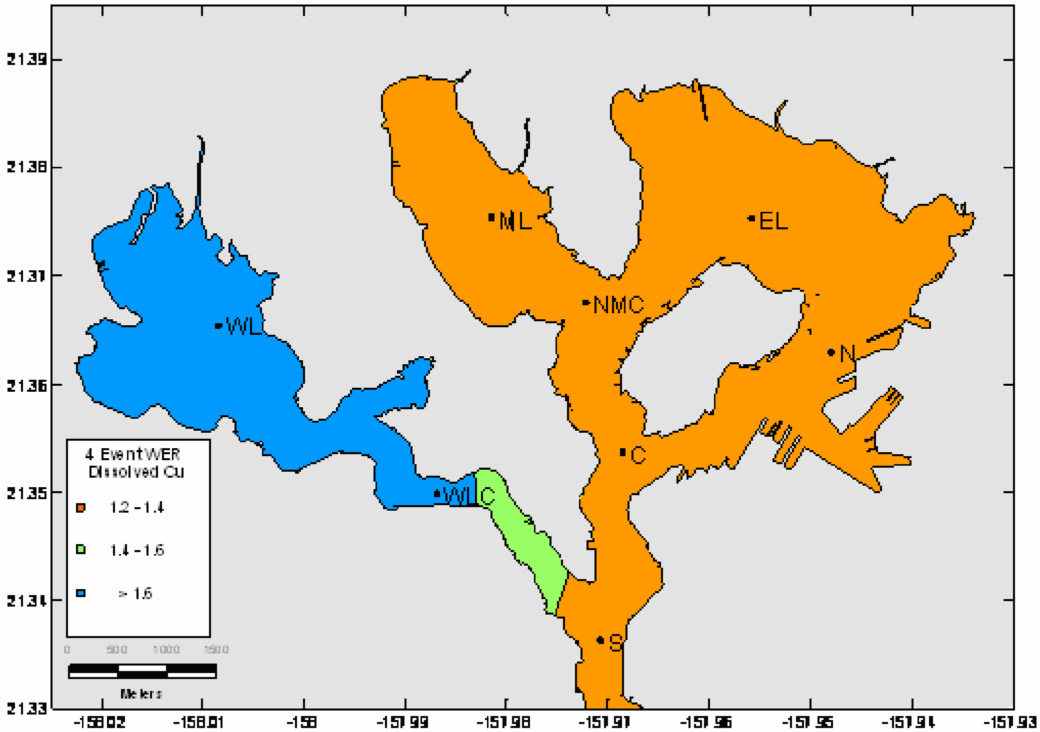


Figure 17. Spatial plot of mean dissolved WERs determined for eight sampling locations from four sampling events in Pearl Harbor, Hawaii, with mussel (*Mytilus galloprovincialis*) embryo toxicity tests.

WATER EFFECT RATIO–SECONDARY SPECIES

A secondary species was tested alongside the mussel tests for two of the four events. Table 21 lists WERs produced from the secondary species testing. Purple sea urchin (*Strongylocentrotus purpuratus*) embryos were tested on Event 2 samples and Pacific oyster (*Crassostrea gigas*) embryos were tested on Event 4 samples. Sea urchin WERs were extremely close to mussel WERs, differing by 2, 4, and 7% for nominal, total recoverable, and dissolved WERs, respectively (Figure 18). Measured mussel WERs were lower than sea urchin WERs, suggesting the primary species WERs are more conservative. Differences, however, were not statistically significant in t-tests, with resulting p-values of 0.371, 0.714, and 0.951 for nominal, total recoverable, and dissolved comparisons, respectively.

Pacific oyster WERs were also very similar to those determined with the mussels, with nominal, total recoverable, and estimated dissolved WERs differing by less than 5, 3, and 3%, respectively, with no significant difference apparent from t-tests ($p = 0.270$, 0.401, and 0.401, respectively) (Figure 19). With three of the eight samples removed from the data set because of flagged control data (<70% normal survival) associated with the first of the two test batches (samples N, S, C), oyster and mussel WERs differed by 9, 10, and 10% for the remaining five samples tested with both species, and no significant differences were detected ($p = 0.194$, 0.429, and 0.429, respectively).

Table 21. Nominal, total recoverable, and dissolved WERs determined from toxicity tests with purple sea urchin (*Strongylocentrotus purpuratus*) embryos for Event 2 (October 2005) and Pacific oyster (*Crassostrea gigas*) embryos for Event 4 (May 2006) at eight sites in Pearl Harbor, Hawaii.

Test Organism	Sampling Event #	Sample ID	Nominal	Total Recoverable	Dissolved
Sea urchin	2	N	1.26	1.44	1.16
	2	S	1.39	1.42	1.12
	2	C	1.41	1.48	1.16
	2	WL	2.42	2.36	1.72
	2	ML	1.72	1.91	1.52
	2	EL	1.79	1.91	1.65
	2	NMC	1.72	1.93	1.65
	2	WLC	2.18	2.19	1.72
	2	Geometric Mean	1.70	1.80	1.44
Oyster	4	N	1.42	1.46	*1.23*
	4	S	1.90	2.00	*1.68*
	4	C	1.82	1.72	*1.45*
	4	WL	1.92	1.70	*1.43*
	4	ML	1.53	1.50	*1.26*
	4	EL	1.70	1.78	*1.50*
	4	NMC	1.41	1.32	*1.11*
	4	WLC	1.99	1.92	*1.62*
	4	Geometric Mean	1.70	1.66	*1.40*

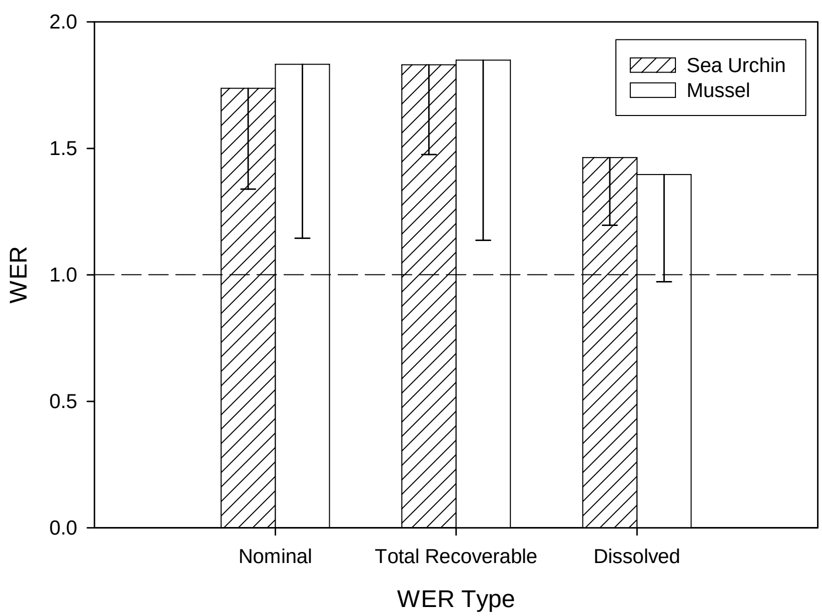


Figure 18. Comparison of mean WERs derived from eight sampling locations for sampling Event 2, in which both mussel (*Mytilus galloprovincialis*) and purple sea urchin (*Strongylocentrotus purpuratus*) were individually tested.

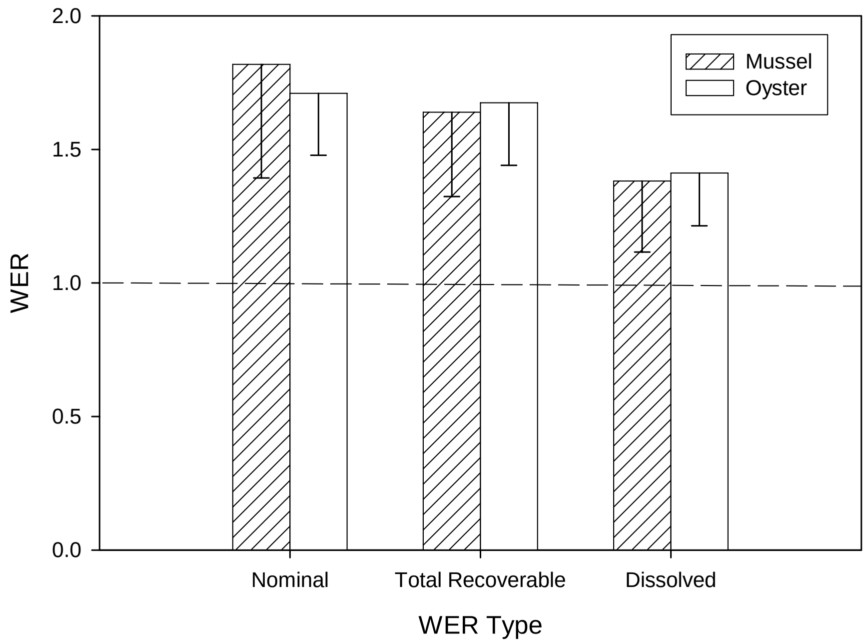


Figure 19. Comparison of mean WERs derived from eight sampling locations for sampling Event 4, in which mussel (*Mytilus galloprovincialis*) and Pacific oyster (*Crassostrea gigas*) embryos were individually tested.

WATER QUALITY CHARACTERISTICS

TSS in site water were always higher than in lab water (Table 22). Site water TSS concentrations averaged 1.92 ±1.43 mg/L (range = 0.50 to 5.96 mg/L) over the four sampling events, while GC lab water TSS concentrations averaged 0.13 ±0.22 mg/L (range = 0 to 0.38 mg/L). The low TSS in lab water is expected, as this water is filtered before use. TSS concentrations were similar for Events 1, 2, and 4, but two to three times higher for Event 3, which was associated with a rain event. Sample locations WL and WLC always had the highest TSS concentrations, while no clear spatial trend was apparent among the other sample locations (Figure 20).

Generally, DOC concentration in the site water were relatively low, averaging 1.92 ±0.59 mg/L (range = 1.20 to 3.69 mg/L) for the four events (Table 23, Figure 21). Overall, site water DOC concentrations appeared lower than laboratory water DOC concentration, which averaged 2.21 ±1.29 mg/L and 2.52 ±1.36 mg/L for GC and SIO lab waters, respectively. The relatively high values measured for the lab waters were primarily driven by values exceeding 4 mg/L associated with Event 3.

A positive relationship between EC50 values and TSS concentration was highly significant ($p<0.05$) for each of the four sampling events (Table 23). For the first three events combined, correlation coefficients (r) were 0.755, 0.726, and 0.683 for TSS correlations between nominal, total recoverable, and dissolved EC50s, respectively. Data from all four events yielded correlation coefficients of 0.737 and 0.671 for nominal and total recoverable EC50s, respectively, but could not be calculated for dissolved. For the most part, no correlation was observed between EC50 values and DOC concentration.

Table 22. TSS, DOC, and TOC for ambient lab and site water samples used in toxicity testing. The mean and SD are calculated for each event.

Water Type	Sample ID	Event 1			Event 2			Event 3			Event 4		
		TSS	DOC	TOC	TSS	DOC	TOC	TSS	DOC	TOC	TSS	DOC	TOC
Lab	SIO	0.58	2.42	-	0.15	1.90	-	0.00	4.44	5.43	0.00	1.33	-
Lab	GC	0.38	1.63	-	-	1.54	-	0.00	4.15	4.21	0.01	1.51	-
Site	N	1.86	2.14	2.67	1.30	1.31	1.57	1.68	3.69	6.30	1.08	3.31	3.63
Site	S	1.10	1.78	2.24	1.92	1.64	2.16	3.78	3.21	3.60	0.77	2.16	4.65
Site	C	0.72	1.70	2.18	0.70	1.28	2.13	2.02	1.69	2.52	0.51	1.20	2.01
Site	WL	2.45	1.37	2.19	4.50	1.97	3.06	5.96	2.24	4.32	2.46	1.99	3.30
Site	ML	1.17	1.93	2.13	0.50	1.68	1.86	4.94	1.60	2.07	0.67	1.47	3.85
Site	EL	1.39	1.78	2.15	1.07	1.41	2.06	2.64	1.29	1.38	0.52	2.33	2.66
Site	NMC	1.22	1.90	2.20	0.81	1.66	1.81	1.88	2.21	2.64	0.57	1.31	2.45
Site	WLC	1.85	2.02	2.23	3.54	1.86	2.69	4.21	2.26	3.72	1.18	2.21	2.83
Site Mean		1.47	1.83	2.25	1.79	1.60	2.17	3.39	2.27	3.32	0.97	2.00	3.17
Site SD		0.55	0.23	0.17	1.46	0.25	0.49	1.58	0.81	1.54	0.65	0.69	0.85

Legend: Units are in mg/L.
Dashed lines indicate no data.

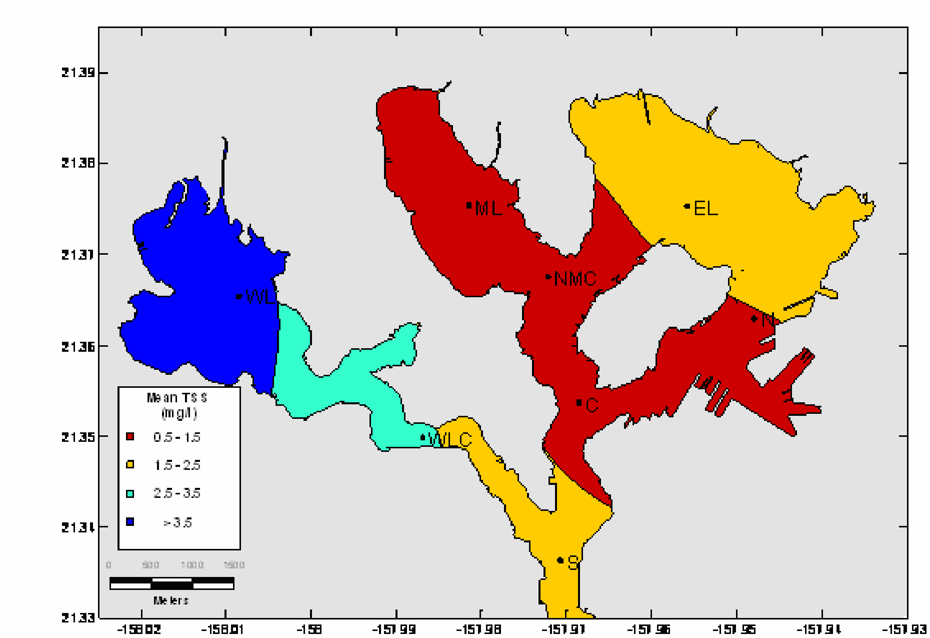


Figure 20. Spatial plot of mean TSS concentrations (mg/L) for eight sampling locations in Pearl Harbor, Hawaii.

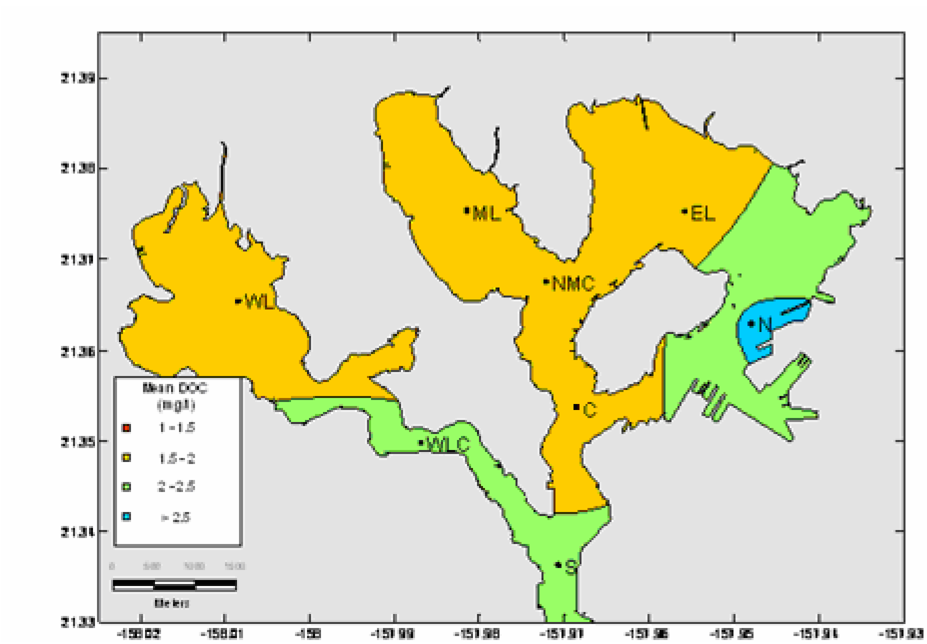


Figure 21. Spatial plot of mean DOC concentrations (mg/L) for eight sampling locations in Pearl Harbor, Hawaii.

Table 23. Correlation coefficients (r) from linear regression analyses between nominal, total recoverable, and dissolved EC50s and TSS and DOC by species and sampling event.

Parameter	Event	Test Organism	*n*	Correlation coefficient [r] Nominal	Total Recoverable	Dissolved
TSS	1	Mussel	12	**0.884**	**0.587**	**0.778**
	2	Mussel	12	**0.953**	**0.902**	**0.911**
		Sea urchin	12	**0.875**	**0.775**	**0.691**
	3	Mussel	11	**0.898**	**0.884**	**0.792**
	4	Mussel	12	0.492	**0.639**	-
		Oyster	12	0.387	0.553	-
DOC	1	Mussel	12	0.342	0.032	0.032
	2	Mussel	12	0.422	0.429	0.513
		Sea urchin	12	0.167	0.118	0.055
	3	Mussel	11	**-0.724**	**-0.715**	**-0.799**
	4	Mussel	12	0.241	0.342	-
		Oyster	12	0.155	0.281	-

Legend: Bold values are statistically significant ($p<0.05$).
Dashed line indicates no data.

WATER QUALITY PARAMETERS

Water quality parameters (e.g., pH, dissolved oxygen, temperature, and salinity) for each of the toxicity test solutions were recorded daily and are provided in Appendix G. Control and copper spiked test solutions differed negligibly. Table 24 lists the mean control data for each sampling event. The pH, temperature, and dissolved oxygen measurements varied little. Salinity was generally similar among sampling locations, with somewhat lower measurements sometimes observed in the L samples. Although salinity averaged 33.6‰ for the four events, Event 3 provided the lowest salinities overall, due to the 1.7 inches of rainfall that occurred during that sampling event. The ML sample had a particularly low salinity (26.3 ‰) during that event.

Table 24. Summary of water quality parameters in controls by sampling event.

Parameter	Event 1 Mean	SD	CV (%)	Event 2 Mean	SD	CV (%)	Event 3 Mean	SD	CV (%)	Event 4 Mean	SD	CV (%)
pH (SU)	7.9	0.02	0.29	8.0	0.02	0.27	8.0	0.04	0.55	8.1	0.11	1.32
Temp. (°C)	18.3	0.26	1.44	15.1	0.37	2.44	18.0	0.14	0.79	18.2	0.21	1.14
D.O. (mg/L)	7.5	0.26	3.45	7.6	0.12	1.57	7.5	0.13	1.67	6.9	0.11	1.55
Salinity (‰)	33.6 (32.2-34.3)	0.87	2.58	34.1 (31.6-35.3)	1.25	3.66	31.6* (26.3-32.9)	2.20	6.95	33.1 (32.2-34.0)	0.76	2.28

AMBIENT COPPER

Table 25 lists all ambient copper concentrations for lab and site water samples. Ambient copper concentrations in site water averaged 0.62 ±0.25 and 0.78 ±0.30 µg/L for dissolved and total recoverable measurements, respectively, which resulted in an overall dissolved to total ratio of 0.793. GC laboratory water concentrations were lower than site water samples (dissolved average = 0.10 µg/L), but SIO lab water used for the reference toxicant tests consistently possessed the highest dissolved copper concentration (average = 2.40 µg/L) (Figure 22).

Table 25. Dissolved and total recoverable copper concentrations measured in unspiked (control) laboratory and site water samples.

Water Type	Sample ID	Ambient Copper (µg/L) Event 1 Dissolved	Event 1 Total	Event 2 Dissolved	Event 2 Total	Event 3 Dissolved	Event 3 Total	Event 4 Dissolved	Event 4 Total
Lab	SIO	1.40[a]	1.40[b]	1.40	1.40[b]	1.51	1.51[b]	4.28	4.28[b]
Lab	GC	0.11[a]	0.11[b]	0.11	0.11[b]	0.06	0.06[b]	0.12	0.12[b]
Site	N	0.85	0.79	0.63	0.72	1.30	1.69	0.55	0.76
Site	S	0.41	0.25	0.53	0.54	1.02	1.05	0.49	0.59
Site	C	0.71	0.65	0.50	0.60	1.03	1.31	0.55	0.69
Site	WL	0.34	0.45	0.44	0.60	0.74	0.90	0.55	0.70
Site	ML	0.59	0.60	0.52	0.68	0.82	1.36	0.54	0.71
Site	EL	0.61	0.77	0.50	0.64	1.00	1.32	0.58	0.76
Site	NMC	0.01	0.69	0.54	0.66	0.91	1.12	0.51	0.67
Site	WLC	0.37	0.51	0.40	0.51	0.60	0.87	0.57	0.68

[a]Samples lost, therefore, ambient concentrations from Event #2 were used for toxicity test calculations.
[b]Because lab water samples were filtered prior to testing, the dissolved value was used for the purposes of total recoverable toxicity test calculations.

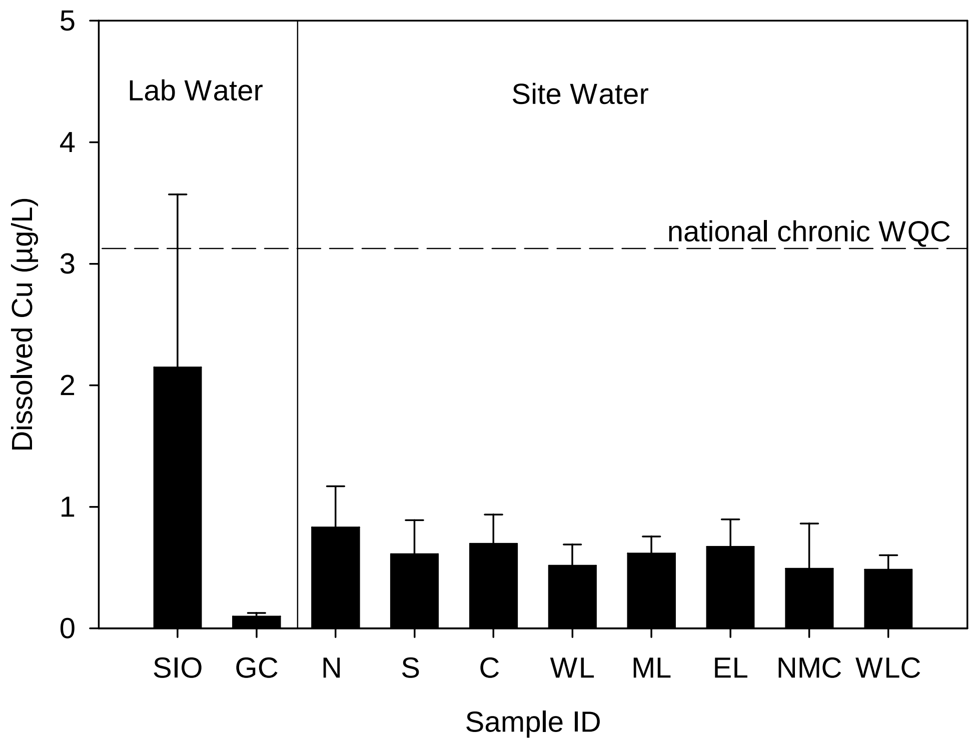


Figure 22. Mean (± 1 SD) dissolved copper concentrations in ambient (unspiked) lab and site water samples for four sampling events in Pearl Harbor, Hawaii.

DISCUSSION

Variability of WERs over Space and Time

The results of this study suggest that water quality characteristics in Pearl Harbor, Hawaii, protect representative organisms against copper toxicity to a higher degree than typical lab water used in WQC development (USEPA, 1985a). Therefore, implementation of the WER for copper derived from this study in State WQS and/or NPDES permits would provide the level of protection intended by USEPA, while also providing a realistic regulatory baseline to those facilities that discharge into Pearl Harbor.

The study resulted in a final (geometric mean of all samples) total recoverable WER of 1.69 and a final dissolved WER of 1.40 for the harbor as a whole, when data from all four sampling events were considered. The total recoverable WER closely approximated the final nominal WER of 1.70, while the dissolved WER averaged 83% of the total recoverable. In all cases, the geometric mean was lower than the arithmetic mean, suggesting that the geometric mean derived values are more conservative.

Based on geometric means of the eight sampling locations in Pearl Harbor, total recoverable and dissolved WERs increased slightly as the study progressed, peaking with Event 3, and then falling back to an average magnitude for the fourth event (Figure 11). WERs from the third event were statistically different from the first event, but otherwise no statistical differences were observed among events (significance level = 0.05). Besides relatively high WERs, Event 3 was also characterized by a rain event that delivered 1.7 inches of rain during the sampling period, and had the highest DOC (average = 2.27 mg/L) and TSS (average = 3.39 mg/L) concentrations. Rain did not fall on Pearl Harbor during the other three events.

WL and WLC samples always yielded the highest and second highest WERs, respectively. Reports of relatively high nutrient concentrations (e.g., phosphorus) have been made in WL previously (Evans et. al, 1974). Interestingly, however, DOC concentrations associated with WL and WLC were no higher than other sampling locations during this study (Table 22).

Santore et al. (2001) have shown that copper ions in the dissolved fraction form complexes with DOC and, consequently, reduce their bioavailability to aquatic organisms. This demonstrated relationship led to the development of a regression-based model that can be used to predict dissolved copper EC50 values for *Mytilus* based on ambient DOC concentration to within a factor of 2 (Arnold et al., 2006), thereby potentially simplifying the process for deriving site-specific criteria for copper.

Regardless of the association demonstrated elsewhere, a clear positive correlation between EC50 and DOC concentration was not readily observed in this study (Table 23). A very good correlation, however, was observed between TSS and EC50, with statistically significant relationships observed for all four events (Table 23).

Correlation between TSS and EC50s are expected, as the presence of particulates provides binding sites that can potentially decrease copper bioavailability, and therefore, observed toxicity to organisms (Erickson et al., 1996). Therefore, sites with relatively high TSS concentrations may be associated with relatively high WERs. TSS concentrations for a WER study in south San Francisco Bay, for example, averaged 28 mg/L (an order of magnitude higher than those observed in Pearl Harbor), and yielded relatively high total recoverable and dissolved WERs of 3.66 and 2.77, respectively (City of San Jose, 1998).

Prediction of WER Using DOC

As mentioned previously, a positive relationship between dissolved EC50s for copper toxicity tests conducted with *Mytilus* embryos and DOC concentration has been shown for several water bodies (Arnold et al., 2006), and has been proposed as a means of deriving site-specific criteria until a saltwater Biotic Ligand Model is developed. The relationship is described by the equation $EC50 = 11.22*DOC^{0.60}$ ($p < 0.0001$, $r^2 = 0.76$, $n = 75$; Arnold et al., 2006). Using a modification to this equation for deriving the WER directly, DOC concentrations measured from samples for this study were used to predict WERs (Figure 23). In this study, measured WERs were slightly more conservative than those predicted by the model. On a geometric mean basis for each event, predicted

WERs were higher than measured WERs by a factor of between 1.08 and 1.33, well within the factor of 2 boundary that the model is expected to achieve (Arnold et al., 2006).

Except for Event 3 (r = 0.831, p <0.05), correlation between individual measured and predicted WERs was generally not apparent, which may be due to error associated with the DOC measurements or the inability for the model to predict precisely within very small ranges. The model incorporates EC50s based on DOC concentrations ranging from <1 to 12 mg/L. The DOC concentrations in this study, however, were relatively low (mean = <2 mg/L) and generally varied by less than 1 mg/L within a sampling event. It is also important to note that even the sample locations that yielded the highest WERs (e.g., WL and WLC) were relatively similar to the other sample locations, with no statistical differences observed.

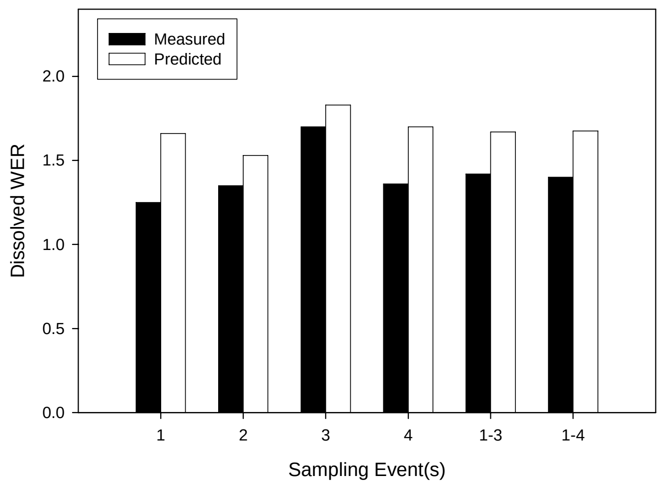


Figure 23. Measured dissolved WERs (geometric mean of eight sample locations) from mussel (*Mytilus galloprovincialis*) embryo toxicity tests for the four sampling events and predicted dissolved WERs using EC50-DOC regression equation by Arnold et al. (2006).

Laboratory Water Suitability

GC lab water used in this study resulted in data that compared more favorably to other WER studies that also used *Mytilus sp.* than did the SIO dilution water used for the reference toxicant tests, making it more relevant for calculation of the final WERs. The geometric mean of dissolved GC lab water EC50s determined in this study was 6.66 µg/L, while the geometric mean of dissolved EC50 values for lab waters from two separate WER studies for South San Francisco Bay were 6.3 and 6.9 µg/L for 1997 and 1991 studies, respectively (City of San Jose, 1998). The San Francisco Bay studies also used GC lab water for WER calculation. A number of data from the San Francisco Bay studies, as well as previous data that used GC lab water for copper EC50 determination (e.g., Martin, Osborn, Billig, and Glicksatein, 1981), are also being used in copper WQC derivation (USEPA, 2003).

In contrast, the geometric mean of dissolved EC50s from SIO water was 7.73 µg/L. Although SIO water was used as a lab water in a WER study for San Diego Bay (Rosen, Rivera-Duarte, Kear-Padilla, and Chadwick, 2005), that study yielded EC50s (geomean = 6.42 µg/L) closer to those representative of GC water. In this study, SIO lab water served as the dilution water for the reference toxicant tests with copper, as the testing laboratory typically uses SIO lab water for development of its control charts used for laboratory quality control purposes. The appropriateness of SIO water as a lab water based on these results is questionable, considering factors such as elevated EC50 compared to other lab waters, the presence of elevated ambient copper (which could be caused by the presence of metal fittings in the filtering system at SIO), elevated DOC concentrations, and a few other data quality concerns.

Confirmation of Results with Secondary Species

Tests with a confirmatory (secondary) species were conducted alongside the mussel tests for two of the four events. Sea urchin dissolved EC50s in GC lab water (12.54 µg/L) compared very closely with the SMAV reported for this species (12.81 µg/L) in the draft national toxicity data set for copper (USEPA, 2003), further illustrating the relevance of the laboratory water selected, repeatability of the test method, and good laboratory performance. The sea urchin WERs compared very closely with those of the concurrently tested mussel batch, with the geometric means of the eight sample locations differing by factors of 1.02, 1.05, and 1.07 for nominal, total recoverable, and dissolved WERs, respectively.

To meet minimum requirements, the confirmatory species WER must be within a factor of 3 of the primary species WER (USEPA, 1994b), which was easily achieved with the sea urchins. Interestingly, although the sea urchin total recoverable WER were slightly higher (by 5%) than the mussel WER, the reverse was true based on dissolved concentrations (7% less). Typically, less sensitive species are expected to yield lower WERs (USEPA, 1994b), but the relatively small difference in copper sensitivity between these particular species may explain the lack of observed differences.

Pacific oyster total recoverable EC50 values in GC lab water (12.16 µg/L) were similar to the SMAV (10.96 µg/L) proposed in the draft national toxicity data set for copper (USEPA, 2003) and the SMAV (17.84 µg/L) reported in the USEPA's 1995 Addendum to the copper WQC (USEPA, 1995a), once again showing relevancy to the laboratory water and normal sensitivity of the test method.

The geometric mean of the Pacific oyster WERs associated with Event 4 were less than 5% different from the Event 4 mussel geometric means for nominal, total recoverable, and dissolved measurements, indicating that the response of the oyster successfully confirmed the mussel WERs reported for that event. In this case, all measured WERs were slightly higher for the more sensitive species, as expected.

Dissolved Data from Event 4

Inspection of the dissolved copper measurements associated with Event 4 invalidated those data. Overall, dissolved measurements were very high and showed no evidence of a trend with increasing nominal copper concentration, while total recoverable data did show evidence. Closer inspection of the problem revealed that a contamination was caused by a syringe used for filtering these samples, resulting in artificially high concentrations. Therefore, these data were not used in the final analysis.

To estimate the dissolved WER for Event 4, however, the dissolved:total ratio among WERs for the previous three events was used to calculate the expected dissolved WERs from the total recoverable data. Dissolved:total WER ratios averaged 0.843 ±0.158, resulting in a relatively low coefficient of variation of 17%. This resulted in a dissolved WER of 1.36 for Event 4, which is consistent with the other events, yet produces a slightly more conservative final dissolved WER of 1.40 in comparison to the final dissolved WER of 1.42 calculated from Events 1 through 3 alone. While the final WER could be based on the first three events (USEPA, 1994b), use of the estimated values for Event 4 results in a more conservative and, therefore, potentially more preferable WER.

No Ambient Toxicity

Throughout the study, no toxicity from the unspiked site water samples collected in Pearl Harbor was ever observed. Percent normal survival exceeded 85 ±6.6%, on average, for mussel embryos (Figure 4-3, Table 4-4). This level substantially exceeds minimum test acceptability requirements for controls (>70%) and equates to 99 ±5.5% normal survival, when the data are expressed relative to lab water control performance. Although development in some site water samples was significantly higher than laboratory water samples, indicating better development in the site water, at no time were they significantly lower, or toxic. Sea urchin and oyster embryo data resulted in similar relationships, supporting the absence of ambient toxicity.

The observation of no ambient toxicity is significant because of the high sensitivity of the toxicity test endpoints used in this study. Embryo-larval development success of echinoderms and bivalves is reportedly sensitive to a variety of contaminants of concern, particularly metals such as copper and zinc (Bay, Burgess, and Nacci, 1993; Phillips, Anderson, and Hunt, 1998; Phillips et al., 2000; Rosen et al., 2005).

The presence of no ambient toxicity was complemented by low concentrations of copper consistently measured in ambient surface water samples throughout this study. Dissolved copper concentrations were always well below USEPA's current ambient WQC for copper of 3.1 µg dissolved Cu/L (USEPA, 1995a), and averaged only 0.62 µg/L (Table 24, Figure 22). The highest concentrations measured were associated with Event 3 (January 2006, average = 0.93 µg/L), which was associated with a relatively strong rain event (1.7 inches). Therefore, it appears that regardless of season or conditions, current copper loading to Pearl Harbor does not result in toxicity or elevated concentrations in the receiving environment.

CONCLUSION

Final WER and Site-Specific Criterion

According to the USEPA Guidance (USEPA, 1994b), sample locations can be considered one site, and therefore combined into one final WER, if they are sufficiently similar or within a factor of 3. Mean total recoverable and dissolved WERs among the sample locations differed by factors of 1.71 and 1.37. The difference between the highest and lowest WERs for the study as a whole, however, resulted in differences of factors of 3.06 and 2.08 for total recoverable and dissolved WERs, respectively.

Greater variability of total recoverable WERs compared to dissolved WERs was observed in this study, as evidenced by higher CVs (Table 20) for the former. Total recoverable WERs are expected to be more variable, particularly in the presence of varying concentrations of TSS and/or total organic carbon (TOC) concentration, as they can affect the levels of particulate nontoxic metal. It is for this reason that WQC are expressed as dissolved metal and that dissolved WERs are more suitable for derivation of site-specific criteria.

The relatively low variability of the dissolved WERs suggests that the final WER should be expressed as the geometric mean of all individual WERs determined. Combining the sample locations into one site is further substantiated by the absence of statistical differences among either total recoverable or dissolved WERs among sample locations.

The final WER is subsequently multiplied by the relevant WQC. Currently, WQC for copper are expressed in terms of dissolved metal (USEPA, 1995a), as this is generally considered the more bioavailable and less variable form. Relatively low variability of dissolved WERs in comparison to total recoverable WERs substantiates this notion, as has been observed in other WER studies (e.g., City of San Jose, 1998). Therefore, the dissolved WER is the most appropriate for use in calculation of the site-specific criterion. It can be applied by itself to the national WQC (current chronic criterion = 3.1 μg/L [dissolved]), or in combination with results from additional USEPA promulgated methods for deriving site-specific criteria. Other portions of this report discuss the development of site-specific criteria for copper using the Recalculation Procedure and Translator Study.

SECTION 6

COPPER TRANSLATOR

INTRODUCTION

Objective

It is generally recognized that the dissolved fraction of a metal in an aqueous solution is a better representation of the biologically active portion of the metal than the total recoverable fraction. Therefore, the USEPA Office of Water recommended that dissolved metal concentrations be used to set and measure compliance with WQS. Consequently, total recoverable criteria must be multiplied by a conversion factor or *translator* to obtain the dissolved criteria. As explained in USEPA guidance, “The translator is the fraction of total recoverable metal in the downstream water that is dissolved; that is, the dissolved metal concentration divided by the total recoverable metal concentration.” (USEPA, 1996a).

Many different water properties influence the ratio of dissolved metal to total recoverable. Important factors include water temperature, pH, salinity, TSS, TOC, DOC, as well as concentrations of other metals and organic compounds that compete with the metal ions for binding sites on particulates. It is difficult to predict the result of such complex chemistry, but it is recognized that these factors may affect the translator and may need to be factored into its calculation. In this study, the effect of water temperature, pH, salinity TSS, TOC, and DOC on the partitioning of copper were examined.

The study examined the partitioning of copper in mixtures of discharge effluent and ambient receiving water during four separate sampling events and three preliminary sampling events. Factors that were critical to the success of the field design included the parameters for measurement, location of the sampling stations, sampling schedule, number of samples collected, use of appropriate sampling techniques, and the data analysis and translator calculation. The following subsections discuss the procedures followed. Guidance on each of these critical study factors was provided in the “The Metals Translator” guidance document (USEPA, 1996a).

Approach

EPA guidance on the translator studies allows flexibility, including several different methods for conducting the study. While the guidance is not prescriptive for every scenario or discharge type, its intent is to capture the partitioning that would occur after the discharge flow enters the receiving water. Examples are given in the guidance for various scenarios involving mixing zones, in which case, the samples are taken at, or beyond, the edge of the mixing zone (i.e., the point where the discharge is regulated). Since no mixing zone currently exists in the Shipyard permit, the point of regulation is end-of-pipe; therefore, the translator developed was based on samples that are representative of mixing near the discharge point.

Sample Collection

Sampling frequency was based on two primary factors: (1) expected variability in the receiving environment, and (2) expected variability in the discharge related to dry dock operations. The flow in the harbor is primarily controlled by tides and wind; there are no idealized “critical-flow” or “design” conditions as might be defined in a river system. A translator should be tied functionally to any important environmental physical or chemical variables (e.g., TSS, TOC).

The most significant variation in receiving water conditions would be induced by tidal flow and wind variability, as well as changes in freshwater inflow into the harbor as a result of rainfall events. Variability in dry dock discharges was also expected to occur primarily in relation to wet and dry weather conditions, and secondarily in relation to operational processes. These influences would be expected to alter salinity, pH, temperature, TSS, TOC, and DOC, which in turn could significantly effect copper partitioning.

A higher number of sampling events would ensure that a greater range of parameter variability would be captured. Therefore, samples analyzed for this study were collected during four sampling events in March 2005, October 2005, January 2006, and May 2006 (Table 26). Efforts were made to perform at least one sampling event during a rain storm to capture variation in receiving water conditions related to freshwater runoff. Thus, the sampling frequency within each event attempted to span the range of processes expected in the receiving waters and dry docks.

Table 26. Dates of sampling events, including type and number of mixtures processed.

Sampling Event	Sample Matrix	DM/TRM Sample Pairs
March 15-18, 2005	Effluent Ambient Mixture	2 3 4
October 18-20, 2005	Effluent Ambient Mixture	2 3 4
January 23-27, 2006	Effluent Ambient Mixture	2 3 4
May 15-19, 2006	Effluent Ambient Mixture	2 3 4
All Events	Effluent Ambient Mixture Total	8 12 16 36

Because of the lack of a specified mixing zone and/or dilution factor, the location of sampling sites was somewhat more difficult to determine. Preliminary sampling in the area indicated that receiving water concentrations were generally well below ambient water quality criteria. This, and the fact that the effort was directed toward a discharge permit rather than a harbor-wide, site-specific translator, argues that the translator would focus on the conditions in the near-field mixing zone where the Shipyard permit compliance objectives will be applied. In accordance with the guidance, effluent samples were mixed with the ambient water (the same water used in the WER study) and the total and dissolved metals levels determined.

The proposed mixing ratio based on the preliminary analysis is 1:1 (effluent: ambient). This mixture provided a reasonable indication of how the discharged metals will partition close to the point of discharge, which is the appropriate place to develop the translator since the discharge is currently regulated at the end-of-pipe. Effluent was collected from dry docks 2 and 4 (DDR2 and DDR4; see harbor map and inset Figure 10).

Ambient seawater was collected at station locations in close proximity to both dry docks (South ambient station near DDR4 and North ambient station near DDR2) and at a station located in between both (Central ambient station). Two ambient/effluent (1:1) mixes were made from each effluent sample. DDR2 was mixed with North and Central ambient samples, and DDR4 with South and Central ambient, for a total of four mixtures during each event.

Each sample was characterized for its copper partitioning components, using trace metal clean methods for analysis: TRM, DM, and particulate metal (PM). A split of each sample into two parts was required, one part to analyze for TRM and the other for DM, while PM was determined as the mathematical difference of the TRM and DM (USEPA, 1996b).

Samples were also analyzed for ancillary parameters important to understanding the partitioning that occur once the effluent mixes with receiving water, including TSS, TOC/DOC, oxygen, salinity, temperature, and pH. These measurements were performed on whole ambient and whole effluent samples and the ambient/effluent (1:1) mixtures.

Per the guidance, a translator should be tied functionally to any important physical or chemical variables (e.g., TSS, TOC) to assess spatial variability. Linear regressions were performed for these different variables in comparison to the translator (fraction of dissolved copper in total copper) to assess whether any of these variables correlate significantly to the partitioning of the metal. If no relationship exists, the translator will be calculated using the geometric means from the combined individual samples.

The new recommended permit limit for copper (excluding any consideration of WER at this point), expressed as total recoverable copper, will be calculated by the ratio of the existing permit limit (adopted directly from dissolved copper WQS) to the translator value (average fraction of dissolved in total copper).

RESULTS AND DISCUSSION

On average, the difference in the characteristics of effluent and ambient waters (Table 27) was insignificant. Effluent temperature was, on average, slightly elevated above ambient within 6%; pH and salinity were consistently lower, but only by 3 and 7%, respectively. A certain percentage of this difference can be attributed to instrument variability. Similar or greater variability could also be observed at any single ambient site during the course of a tidal cycle.

Since the pH and salinity differences are in almost all cases lower than ambient waters, these differences are most likely the result of some freshwater intrusion into the dry dock system. The consistent temperature elevation is most likely a remnant heat exchange characteristic of the dry dock water storage reservoir. Such small differences are chemically and biologically insignificant.

To obtain data under as broad a spectrum of conditions as possible, water samples were collected over the period of a year in the Fall, Winter, and Spring. Table 27 summarizes the key variables in the ambient and effluent samples and Table 28 summarizes those for the ambient/effluent (1:1) mixture samples. The translator may be directly determined by measuring dissolved and total recoverable copper in effluent and receiving water mixtures. If the dissolved copper fraction is a function of some other water property (e.g., TSS), then the translator is derived using a partition coefficient. TSS in the ambient samples generally was below 4 mg/L.

During the first two events, surface TSS (1-meter depth) was consistently half the concentration compared to levels at depth (1 to 2 meters from the bottom). During Event 3, this relationship was reversed. Surface TSS was higher than at depth. Event 3 was conducted during a rainstorm, ~1.7 inches of rain fell during the sampling day and the higher TSS at the surface was associated with a freshwater lens and a receiving water mixing zone just below it. Event 4 concentrations were mixed, North and South ambient slightly higher at the surface and Central twice as high at the surface than at depth. The mean TSS value of 6.78 mg/L measured in Event 1 for the effluent/

ambient mixture of dry dock 4:Central (DD4:C) was for this study abnormally high (Table 8). It was higher than TSS measured in the Central ambient or DD4 discharge samples alone and was therefore not included in translator calculations or in the linear regression analysis of TSS influence on the translator. Excluding that value, TSS values spanned a rather narrow range; effluent/ambient mixtures averaged 1.37 ±1.19 mg/L (not including DD4:C), ambient surface averaged 1.45±0.9 mg/L, and ambient deep averaged 1.88±1.3, all statistically equivalent.

With such a narrow range, it is not surprising that regression analysis (using raw data and transformed data) did not reveal a significant influence of TSS on the translator. The highest correlation was calculated using log transformed data, $r^2 = 0.19$. Regression analysis was also performed using TOC and DOC data sets, with similar results. Highest correlation was calculated with log transformed data, $r^2 = 0.02$ and $r^2 = 0.03$, respectively. The TSS concentrations observed in this study were below those found in other bays and estuaries in the United States, many with median concentrations in the tens and some in the hundreds of mg/L (CH2M HILL, 2000, 2002; City of San Jose, 1998).[7]

Higher translator values are usually associated with lower TSS concentrations, i.e., less material is available to absorb the metal, so more of the metal will be in the dissolved fraction. Calculating a translator from ambient/effluent mixtures with low TSS levels averaging 1.37 mg/L and median concentrations of 0.72 mg/L therefore constitute near worst-case circumstances, i.e., skewed towards a higher dissolved metal fraction.

The translator is the mean calculated from the dissolved fraction results of the 15 ambient/effluent mixtures. The mean dissolved copper fraction calculated for each of the four events, excluding E#1 DD4:C, were consistent across all events (mean ±SD), E#1 0.62 ±0.18, E#2 0.61 ±0.03, E#3 0.62 ±0.18, and E#4 0.67 ±0.09. The geometric mean calculated from all was 0.62 ±0.05 at the 95% confidence level. Therefore, under most conditions, 62% of the total recoverable copper is in the dissolved fraction, which is a substantially lower fraction than the value applied by the USEPA in the absence of a site-specific translator determination of 0.83.

The sample with the lowest dissolved copper fraction was the excluded E#1 DD4:C sample, 0.42. The sample could possibly have been inadvertently contaminated, yet even if included in the final calculation, would only have lowered the translator from 0.62 to 0.61.

[7] Chadwick and Trefry, 1999.

Table 27. Ambient and effluent water characteristics.

Sample I.D.	Temp. °C	pH	Salinity (psu)
Event #1			
Ambient			
North	23.95	8.00	33.4
Central	23.91	8.00	33.7
South	23.70	8.00	33.9
Effluent			
Dry dock 2	25.2	8.13	27.7
Dry dock 4	28.4	8.13	33.0
Event #2			
Ambient			
North	26.63	8.10	35.1
Central	27.63	8.10	34.9
South	28.03	8.20	34.6
Effluent			
Dry dock 2	27.0	7.79	30.2
Dry dock 4	30.8	7.76	33.7
Event #3			
Ambient			
North	24.44	8.10	32.9
Central		8.10	33.1
South		8.10	33.4
Effluent			
Dry dock 2			
Dry dock 4			
Event #4			
Ambient			
North	25.14	8.20	33.5
Central	25.61	8.20	33.5
South	25.52	8.20	33.1
Effluent			
Dry dock 2	25.7	7.94	33.2
Dry dock 4	26.2	7.61	32.2

Table 28. Copper translator results.

Sample I.D.	TSS (mg/L)	DOC (mg/L)	TOC (mg/L)	Dissolved Cu (µg/L)	Total Recoverable Cu (µg/L)	Translator Dissolved / Total	Comments
E#1 DD2:N	2.43	1.82	1.99	7.6	13.3	0.57	
E#1 DD2:C	3.14	1.92	2.23	7.3	15.5	0.47	
E#1 DD4:C	0.90	1.87	2.10	9.8	11.9	0.82	
E#1 DD4:S	6.78	1.81	1.94	17.5	41.6	0.42	excluded
E#2 DD2:N	0.72	1.31	1.60	3.6	6.0	0.60	
E#2 DD2:C	0.44	1.23	1.32	3.3	5.6	0.59	
E#2 DD4:C	0.63	1.04		5.0	8.5	0.59	
E#2 DD4:S	0.58	1.06	1.10	5.9	8.9	0.66	
E#3 DD2:N	3.26	2.77	2.94	29.1	46.5	0.63	rain storm
E#3 DD2:C	3.79	4.95	4.99	24.0	40.8	0.59	rain storm
E#3 DD4:C	1.43	2.38	3.46	12.6	20.4	0.62	rain storm
E#3 DD4:S	1.36	2.46	3.31	13.3	20.8	0.64	rain storm
E#4 DD2:N	0.43	4.08	4.38	4.7	6.1	0.77	
E#4 DD2:C	0.40	3.13	3.37	4.4	6.1	0.72	
E#4 DD4:C	0.54	3.86	4.47	3.1	5.7	0.54	
E#4 DD4:S	0.45	2.56	2.76	3.1	4.9	0.63	
geo mean						**0.62**	
mean	**1.37**	**2.43**	**2.86**	**9.1**	**14.7**	**0.63**	
sd=	**1.19**	**1.17**	**1.21**	**7.8**	**12.9**	**0.09**	
median=	**0.72**	**2.38**	**2.85**	**5.9**	**8.9**	**0.62**	
n=	**15**	**15**	**15**	**15**	**15**	**15**	
95% C.I.=	**0.60**	**0.59**	**0.61**	**4.0**	**6.5**	**0.04**	

CONCLUSION

A study was conducted to determine the relationship between total and dissolved copper in dry dock effluent entering Pearl Harbor. Water quality criteria for metals are generally based on dissolved metal levels because this value is thought to be the toxic fraction. A translator for copper was calculated from the water chemistry results from 15 effluent and ambient water mixtures collected during four separate sampling events. The copper translator developed in this study can be used to determine the expected dissolved fraction of copper in the dry dock effluent as it enters Pearl Harbor.

A total of 16 samples were collected and mixed 1:1 with ambient harbor water. One sample was excluded from this analysis because of its higher TSS values. Its exclusion did not have a significant effect the resulting translator. The dissolved to total ratio (i.e., the translator) was 62% for copper. The measured ratio was lower than that the 83% proposed by the USEPA, which indicates that of the total copper in the dry dock effluents entering Pearl Harbor, a substantial portion of the copper, 38%, is not in the dissolved fraction.

SECTION 7

DILUTION CREDIT

INTRODUCTION

A final step in the evaluation of the Shipyard NPDES discharges is to incorporate a dilution credit that can be applied to end-of-pipe measurements that are made when reporting monthly discharge monitoring values. The Cornell Mixing Zone Expert System (CORMIX) is a USEPA-approved (USEPA, 1990) steady-state model that was used to conduct a dilution credit analyses. However, in the case of PHNSY&IMF, a dye study must be performed in conjunction with the use of this model to supplement the results and to evaluate shoreline effects that do not allow for the development of a normal discharge plume. A 15-foot zone of initial dilution was established to consider a zone where ambient receiving water is permitted to exceed acute criteria and initial mixing is dominated by turbulence associated with the discharge. The dilution factor at the edge of the 15-foot zone of initial dilution was incorporated into the Shipyard permit calculations.

REGULATORY CONSIDERATIONS

The HIDOH WQS defines Pearl Harbor as a Class A II (HIDOH, 2000) water body, allowing for permitted industrial discharges, provided that the recreational purposes and aesthetic enjoyment of the receiving water be protected. In addition, the standards assert that the State may allow for a limited area around outfalls and facilities for the initial dilution of waste discharges. A zone of mixing can be granted for discharges that are not submerged if certain requirements are met as outlined in HIDOH, 2000 §11-54-09:

The continuation of the function or operation involved in the discharge by the granting of the zone of mixing is in the public interest.

- The public interest is well served by the PHNSY&IMF—it is the State of Hawaii's largest industrial employer, with approximately 4,200 civilian and 700 uniformed military personnel. PHNSY&IMF's primary mission is to provide regional maintenance at the depot and intermediate levels to keep the surface ships and submarines of our nation's Navy "Fit to Fight." Maintenance capabilities include excellence in overhauling, repairing, converting, alteration, refurbishing, defueling, refueling, and decommissioning of Navy vessels. The closure of this facility because of lack of compliance with stringent environmental regulations would move these maintenance activities to other naval facilities in other states, representing a significant impact to the public interest and the State of Hawaii.

(B) *The discharge occurring or proposed to occur does not substantially endanger human health or safety;*

- The PHNSY&IMF is a tightly controlled industrial facility from an environmental, security, and human health perspective—this control extends into the harbor and includes considerations specifically related to the NPDES-permitted industrial discharges. No fishing or recreational activities are allowed near the PHNSY&IMF or the adjacent Naval Station because of security and safety regulations designating most of Pearl Harbor as a Naval Defensive Sea Area (Department of the Navy, 1990). The rest of Pearl Harbor Estuary is under tight control by the U.S. Navy, and all vessels are required to follow strict requirements for movement and operations, which include specific prohibitions for fishing, boating, swimming, or any recreational activities east of Ford Island, including Shipyard facilities in the naval facilities (Commander, Naval Region, Hawaii, 2003). A

State-issued ban on the consumption of fish and shellfish from the Harbor exists because of high levels of PCB (Commander, Naval Region, Hawaii, 2003). However, the PHNSY&IMF does not discharge PCBs. Allowing for a zone of initial dilution would not endanger human health or safety.

(C) *Compliance with the existing water quality standards from which a zone of mixing is sought would produce serious hardships without equal or greater benefits to the public;*

• The water effect ratio and recalculation portions of this study demonstrate that there are no deleterious effects to Pearl Harbor from the dry dock discharges. The Shipyard commissioned an engineering study to modify the dry dock discharges to estimate the costs to submerge and extend the outfalls at the Shipyard; however, it will be on the order of several million dollars and take 5 to 10 years to implement. Aside from the time and economic requirements, the impacts to ongoing naval operations and vessel traffic may render this option unrealistic. Without an appropriate zone of mixing, the current ship maintenance operations at PHNSY&IMF would not be able to comply with existing WQS, and would be forced to cease operations.

(D) *The discharge occurring or proposed to occur does not violate the basic standards applicable to all waters, will not unreasonably interfere with any actual or probable use of the water areas for which it is classified, and has received (or in the case of a proposed discharge will receive) the best degree of treatment or control;*

• The PHNSY&IMF discharge does not interfere with any actual or probable use of the water areas for which it is classified. Fishing and swimming are not allowed near the Shipyard, the consumption of fish and shellfish is prohibited because of PCB contamination, and all recreational activities are prohibited in the areas adjacent to the PHNSY&IMF (Commander, Naval Region, Hawaii, 2003). However, a significant amount of scheduled maintenance/diving activities occur within Shipyard waters that involve diver exposure to harbor waters. This study has shown that the waters within the area of the Shipyard are pristine and are less than ½ the HIDOH water quality criteria of 2.9 µg/L for copper and well below the associated human health criteria of 1,300 µg/L (65 FR 31682).

• The Shipyard personnel constantly strive to ensure that the discharges receive the best degree of treatment or control possible (as documented in Section 3). PHNSY&IMF uses the most effective means of pollution control and continually examines ongoing operations and compares activities to similar facilities and industry practices to find new or alternative practices that can be adopted by the Shipyard.

The other requirements set forth in the Hawaii administrative rules that must be met for the Director, HIDOH, to make a limited allowance for dilution of a discharge include the discharge velocity is greater than 3 meters per second; the discharge enters the receiving water horizontally, and the receiving water depth at the discharge point is greater than zero (HIDOH, 2000). All of these conditions are met by the current Shipyard discharges in their current configurations.

Finally, the regulations state that the zone of mixing should "…provide for a current realistic means of control over the placement and manner of discharges or emissions so as to achieve the highest attainable level of water quality or otherwise to achieve the minimum environmental impact considering initial dilution, dispersion, and reactions from substances which may be considered to be pollutants." (HIDOH, 2000).

METHODS

The Cornell Mixing Zone Expert System (CORMIX) model was used to conduct a dilution credit analyses (Appendix L). Model input parameters were gathered during site visits, from shipyard records and shipyard personnel (Appendix M). Multiple model runs were executed in order to simulate the discharge environment for the outfalls associated with drydock 2 and drydock 4. After multiple iterations, results were generated for outfalls 2a/2b; however, for outfalls 4a and 4b, the discharge environment was too complex to accurately input information into the CORMIX model, so all dilution credit calculations and model runs were based on results from outfall 2a/2b scenarios.

Although accurate field data were gathered, the complex shoreline geometry and ambient environmental conditions may preclude CORMIX from generating accurate predictions of the dilution credit that is applied to the Shipyard permit. Therefore, to ensure compliance and accurate dilution credit calculations, a mixing zone/dye study will be performed by the Shipyard. This study is the reliable way to quantify actual dilution because boundary constraints at Pearl Harbor create uncertainty in the model results. Even in an ideal modeling scenario, CORMIX predictions are specifically limited: "*Extensive comparison with field and laboratory data has shown that CORMIX predictions on dilutions and concentrations are reliable for the majority of cases and are accurate to within about ±50% (standard deviation)*"(USEPA, 1990). A dye study will eliminate any uncertainty associated with the dilution credit calculated from the model results. The CORMIX Model can be used to support the analysis of other conditions that are different from those present during the dye study, such as high/low flow rates, variable currents, and differences in the density of the discharge.

RESULTS

The modeling tool CORMIX, recommended by HIDOH and the State of Hawaii, was used to estimate a dilution credit factor of 2.8 (±1.4) (Appendix L) that will occur at the edge of a 15-foot zone of initial dilution from the Shipyard outfalls. Modeling exercises used an ambient current of 0.02 m/second and incorporated average discharge parameters at the Shipyard. Additional parameters applied to the modeling scenarios are detailed in Appendix M.

For the purposes of the NPDES permit calculations, a dilution credit of 2.8 is used as a surrogate value until the Shipyard completes a mixing zone study to measure the actual dilution credit at 15 feet. This study must be approved and coordinated with appropriate HIDOH personnel. When the dye study is complete, the new dilution credit at 15 feet can be adopted into the permit, replacing the CORMIX modeling result. The final outcome are criteria that will provide the level of protection intended by USEPA (USEPA, 1985a) for Pearl Harbor as well as provide appropriate regulatory control over discharges to the environment.

DISCUSSION

The establishment of a 15-foot mixing zone from the end-of-pipe provides minimal considerations of initial dilution, dispersion, and reactions from substances. The discharge plume from dry dock 2 extends well out into the receiving water, and a 15-foot distance represents the point at which strong directional flow begins to encounter ambient mixing (Figures 24 and 25). At dry dock 4, the effluent is discharged underneath the pier, approximately 40 feet from the edge of the pier. This area is a relatively quiescent area, and the geometry is too complex to simulate any discharge in the area. The only way to understand the zone of initial dilution is to perform a mixing zone/dye study (Figures 26 and 27).

Figure 24. Outfall 2 discharge. The average distance between the pier pilings in this picture is ~7.5 feet.

Figure 25. Outfall 2 discharge with proposed zone of initial dilution.

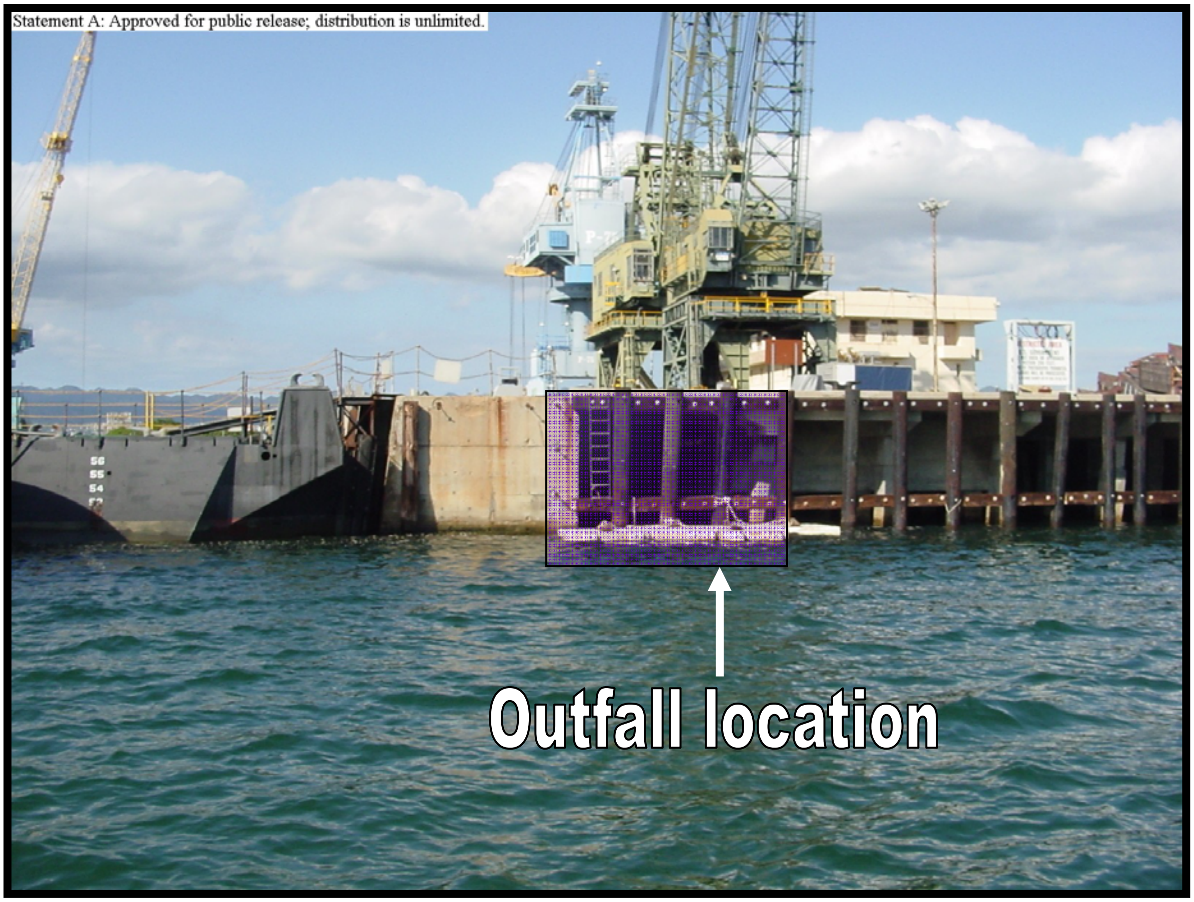


Figure 26. Dry dock 4 discharge.

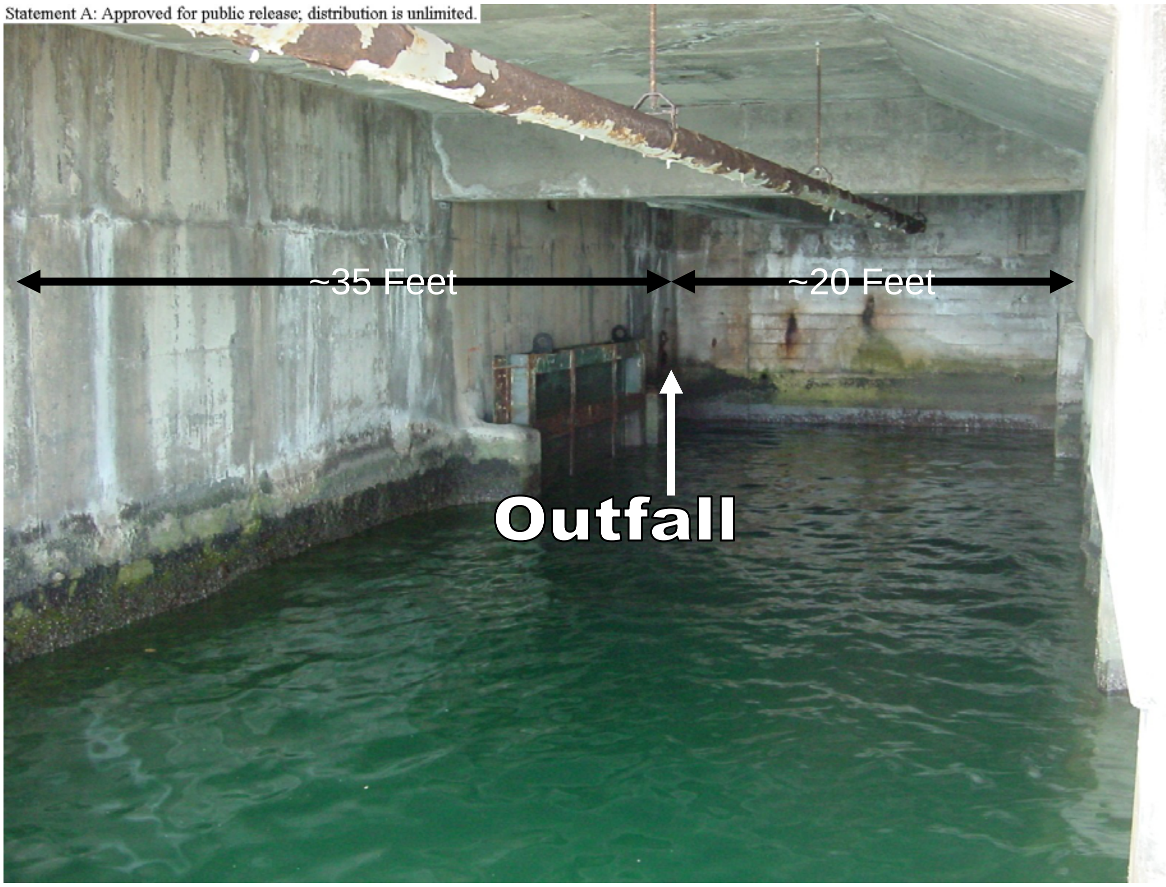


Figure 27. Close-up of dry dock 4 discharge area.

The mixing zone/dye study will help validate model results and update the dilution credit applied to the Shipyard permit. General considerations for the study include a constant dye concentration in the effluent, setting the effluent flow rate at or near its reasonable worst case, and initiating the experiment after the start of an ebb-tide stage. Considering these factors will help to capture critical conditions that impact the discharge.

Measurements for comparing dilutions from the dye study and the CORMIX model results will be made at the 15-foot range from where the discharge plume enters the receiving water and at the end of the hydrodynamic mixing zone.

CONCLUSION

The current discharge configurations at PHNSY&IMF do not contribute to chronic water quality problems at the Shipyard or in the harbor. The regulatory considerations allowing for the Shipyard to incorporate a dilution credit into their NPDES permit are available without significant changes to the Shipyard piping and pumping facilities. The incorporation of a 2.8 dilution credit into the Shipyard permit will enable the Shipyard to comply with environmental regulations and continue as a steward of the environment. This dilution credit will be updated by the Shipyard completing a mixing zone/dye study and updating the permit.

SECTION 8

PROPOSED PERMIT LIMIT

INTRODUCTION

In accordance with the PHNSY&IMF NPDES Permit number HI011230 dated 15 January 2002 (HIDOH, 2002), the Shipyard initiated a study to develop site-specific discharge limitations using appropriate USEPA methods and guidance documents. The study focused on copper limits and a comprehensive characterization and evaluation of the water quality for copper within Pearl Harbor. This study incorporates the results from a recalculation procedure (USEPA, 1994b), a Water Effect Ratio Study (USEPA, 2001), and a Chemical Translator Study (USEPA, 1996a).

An ongoing implementation and evaluation and of Best Management Practices and a harbor-wide evaluation of water quality characteristics throughout Pearl Harbor were performed. A final NPDES permit limit was calculated for PHNSY&IMF that includes a consideration of a dilution credit that will be applied within 15 feet of the Shipyard outfalls. This study supports the final permit limits for acute and chronic copper of 49.3 μg/L and 31.6 μg/L, respectively.

A permit limit was calculated by applying a recalculation procedure following USEPA guidance (USEPA, 1994b) to adjust the current national WQC for copper using a step-wise method that involves corrections, additions, and deletions of species and/or genus to the national toxicity data set, rendering it more representative of species occurring in Pearl Harbor. The procedure addressed outdated USEPA recommended criteria of 2.9-μg/L total recoverable copper (USEPA, 1984a), which is applied in the PHNSY&IMF current NPDES permit for its dry docks (HIDOH, 2002).

The recalculation was performed using a more comprehensive and up-to-date toxicity data set to develop the recommended criteria for acute and chronic exposure, both of which are expressed on a dissolved basis. The recalculation resulted in acute and chronic copper criteria of 7.8 and 5.0 μg/L, respectively.

After the recalculation was completed, a WER study was conducted using embryos of sensitive marine invertebrates to derive a site-specific WQC for copper. The investigation involved extensive toxicity testing associated with four sampling events at eight different locations representing the whole harbor. Based on USEPA guidance (USEPA, 1994b), the study used the Mediterranean mussel (*Mytilus galloprovincialis*) as the primary species and the purple sea urchin (*Strongylocentrotus purpuratus*) and Pacific oyster (*Crassostrea gigas*) as secondary corroborative species. Final nominal, total recoverable, and dissolved WERs were 1.68, 1.71, and 1.42, respectively.

A total of seven surveys were conducted to evaluate the health of the Pearl Harbor Estuary and any associated impacts to the harbor from the PHNSY&IMF. The first three sampling events were considered "preliminary events" because the sampling and analysis work plan had not been approved by the Department of Health, Hawaii (HIDOH). The first three preliminary events focused on the area adjacent to the Shipyard (Figure 28: Stations North, Central and South). After review of the sampling and analysis plan, HIDOH requested the addition of five sampling locations to allow for a complete water-body assessment of the Pearl Harbor Estuary.

Eight stations were sampled throughout the harbor for this study: two in West Loch, two in Middle Loch, one in East Loch, and the original three stations in the vicinity of the Shipyard (Figure 28 and Table 29). During the four "official sampling" events, the three stations in the vicinity of the Shipyard were further subdivided to take surface (1-meter) and depth (13-meter) samples. The four official events occurred on 15–18 March 2005, 18–20 October 2005, 23–27 January 2006, and 15–19 May 2006.

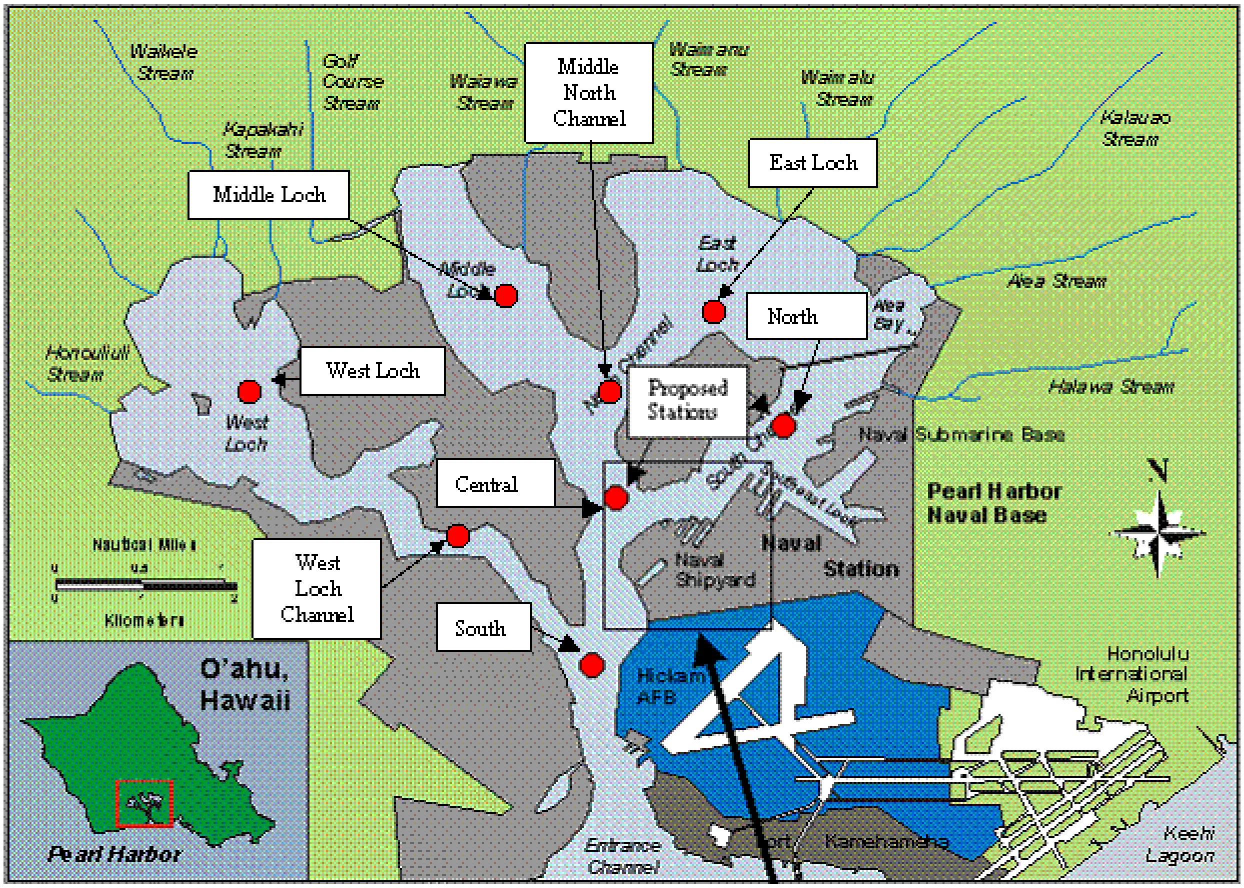


Figure 28. Sampling stations throughout Pearl Harbor, Hawaii.

Table 29. Station locations in Pearl Harbor, Hawaii.

Station	Latitude	Longitude
North	21º 21" 46.6'	157º 56" 52.5'
Central	21º 21" 13.3'	157º 58" 06.6'
South	21º 20" 10.7'	157º 58" 14.6'
West Loch	21º 21" 55.55'	158º 00" 30.38'
West Loch Channel	21º 20" 59.49'	157º 59" 13.09'
Middle Loch	21º 22" 31.32'	157º 58" 53.38'
Middle Loch North Channel	21º 22" 03.08'	157º 58" 19.98'
East Loch	21º 22" 31.19'	157º 57" 20.84'

The consistently low dissolved copper concentrations (overall mean, 0.62 ±0.25 µg/L) measured in the harbor during this study suggest that current copper loading does not result in levels unsafe to the biota, which was corroborated by an absence of ambient toxicity from all samples, and for all species examined throughout this study. During all sampling events, ambient copper concentrations (dissolved) throughout the harbor did not exceed 1.3 µg/L (Figure 29). The highest concentrations occurred during a stormwater event (January 2006) where 1.72 inches of rain was recorded over a 6-day timeframe at the Shipyard. All of the concentrations measured throughout the harbor were less than half of the current Hawaii WQS (2.9 µg/L) and well below the current USEPA WQC (4.8 µg/L) (Figure 29). Although there are distinct differences in ambient copper concentrations between sampling events, the seasonal variability and its associated impacts to the harbor did not exceed ambient concentrations above 1.3 µg/L.

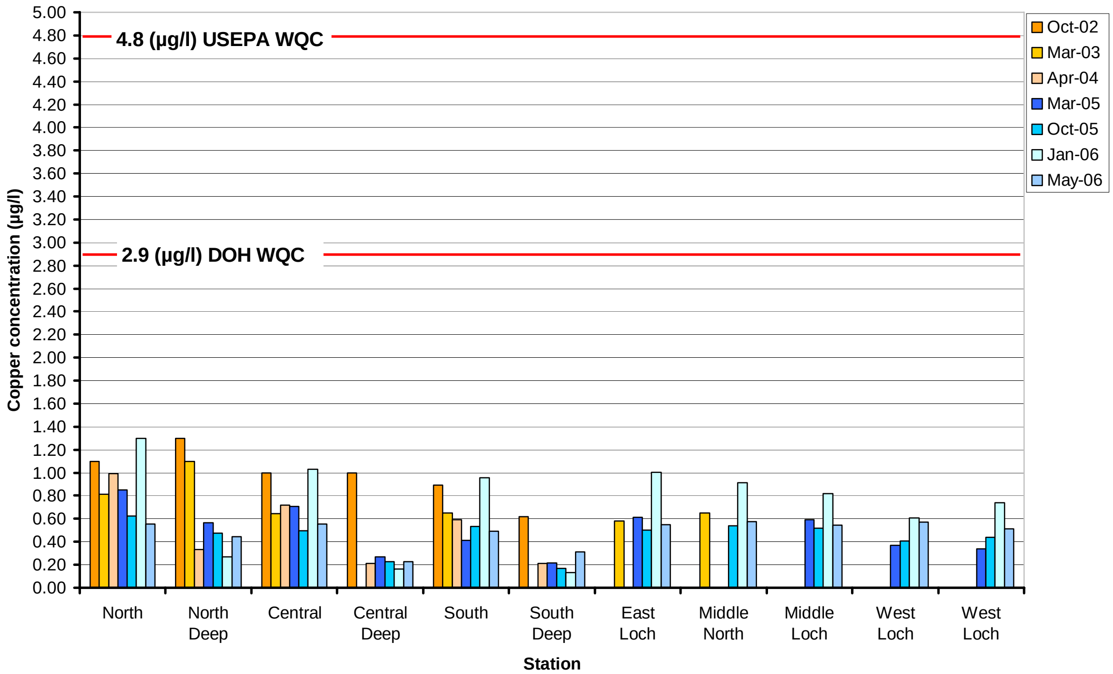


Figure 29. Seasonal dissolved ambient copper concentrations throughout Pearl Harbor Estuary.

Water quality criteria for metals are generally based on dissolved metals levels because this level is thought to be the toxic fraction. USEPA guidance states that total recoverable water quality criteria must be multiplied by a conversion factor or *translator* to obtain the dissolved criteria, which is applied in NPDES permits (USEPA, 1996a). A translator for copper was calculated from the water chemistry results from 15 effluent and ambient water mixtures collected during four separate sampling events.

The dissolved to total ratio was 63% for copper in the Pearl Harbor estuary, which indicates that of the total copper in the dry dock effluents entering Pearl Harbor, a substantial portion of the copper (37%) is not in the dissolved fraction and is not a primary toxicological threat to exposed organisms. The copper translator developed in this study can be used to determine the expected dissolved fraction of copper in dry dock effluents as they enter Pearl Harbor.

PERMIT LIMIT CALCULATIONS AND DISCUSSION

Integrating all of the elements of this comprehensive study, the final permit limit can be expressed as follows:

$$\text{Permit Limit}_{TRM} = \frac{(\text{Recalc WQC}_{DM})*(\text{WER}_{DM})*(\text{DC})}{(\text{CT})},$$

where

TRM = Total Recoverable Metal
Recalc WQC_{DM} = Recalculated Dissolved Metal Criterion
DM = Dissolved Metal
WER = Water Effect Ratio
DC = Dilution Credit applied to discharge
CT = Metal Chemical Translator

The copper limit is calculated for the PHNSY&IMF as follows:

(7.8 µg/L)*(1.42)* (2.8)/(0.62) = 50.0 µg/L Total Recoverable Copper (acute)

(5.0 µg/L)*(1.42)* (2.8)/(0.62) = 32.1 µg/L Total Recoverable Copper (chronic)

Compliance with these standards requires significant efforts upon the part of the Shipyard. As part of this effort, copper concentration measured on monthly NPDES samples from the effluent averaged 20.1 ±20.5 µg/L (n = 62, range 113.8 to 4.4 µg/L) including rain event samples, and 16.3 ±12.4 µg/L (n = 51, range 81.5 to 4.4 µg/L) during dry events. An ongoing effort to evaluate process waste streams and control pollution will continue to be paramount to comply with these low regulatory limits. Based on current data, one-time pass-through, non-contact seawater cooling has an average concentration of 23.2 ±14.9 µg/L total recoverable copper. No BMP can treat this discharge any further, so the Shipyard will have to focus new BMP on controlling any of the other potential sources of copper to comply with these requirements. The effectiveness of any new BMP must be evaluated by appropriate low-level measurement and analytical techniques. The Shipyard chemistry laboratory must train the appropriate personnel and implement special techniques to support these efforts.

SECTION 9

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APPENDIX A

SAMPLING AND ANALYTICAL PROCEDURES

SAMPLING AND MEASUREMENT OF COPPER IN AMBIENT WATERS FOR AMBIENT WATER CHARACTERIZATION, WER, AND TRANSLATOR STUDIES

Sampling protocols followed for all of the waters collected are those of EPA Method 1669, for *Sampling Ambient Water for Trace Metals at EPA Water Quality Criteria Levels* (USEPA, 1996). These protocols include using plastic-made, acid-cleaned bottles and sampling equipment, and "clean-hands/dirty-hands" techniques. The bottles used for collection of ambient samples are made of polyethylene and were purchased already soap- and acid-rinsed. They were rinsed in a class-100 working area with 18-MΩ/cm water, soaked in 15% trace metal grade nitric (HNO_3) acid for 5 days, rinsed and filled with 18-MΩ/cm water, acidified with 200-µL of quartz-still grade HNO_3 (Q-HNO_3), and double-bagged.

Ambient waters were colleted through continuous pumping of surface and subsurface water with a peristaltic pump equipped with a Teflon® diaphragm pump-head and Teflon® tubing. This system is similar to that indicated in Appendix E.2.4 of the metals translator guidance (USEPA 1996); but the Teflon® tubing is lowered to the desired depth and the pump is always onboard. The tubing is fitted with a Teflon® weight to set it to the desired depth. Unfiltered and filtered samples were collected in situ at each station, and the sample collection was preceded by triple rinse with sample water, then overfilling the bottle, rinsing the cap, and discarding the excess sample to leave the water level to the neck of the bottle. Filtration was done in-line with a 0.45-µm pore-size capsule cartridge filter attached to the outlet of the Teflon® tubing. The filter was acid-cleaned, high volume, and all-polypropylene.

Preservation, handling, and analysis of the samples were done in class-100 trace metal clean working areas. The air in these areas is pressure-filtered through 0.3-µm High-Efficiency Particulate Air filters, creating a positive pressure in the working area. The classification 100 indicates the average number of particles per cubic feet per minute in the working area. For the preservation, 2 mL of Q-HNO_3 per liter of sample were added to decrease the pH to less than 2.

Quality assurance included bottle and field blanks. Equipment blanks were not used because field blanks do not indicate contamination. Ambient samples, as well as samples with very low copper concentrations, were treated by liquid/liquid preconcentration with dithiocarbamates following Bruland, Coale, and Mart (1985).

This treatment decreases the amount of salts in the sample, which interfere the measurement, and increases the concentration of copper for better accuracy and precision. Copper concentrations were measured by stabilized temperature graphite furnace atomic absorption (STGFAA) spectroscopy with Zeeman background correction. The standard reference material (SRM) CASS4 (near-shore seawater) from the National Research Council of Canada was used to quantify the recovery of the liquid/liquid preconcentration. Blanks of 1N Q-HNO_3 and the SRM 1643d (trace metals in water) of the National Bureau of Standards were used to evaluate the limit of detection, precision, and accuracy of the STGFAA analysis.

SAMPLING AND MEASUREMENT OF COPPER IN EFFLUENTS, FOR DISCHARGE CHARACTERIZATION, WER, AND TRANSLATOR STUDIES

The sampling protocols followed for the collection of these waters are those of EPA Method 1669 (USEPA, 1996). In this case, these protocols include the use of plastic-made, acid-cleaned bottles and "clean-hands/dirty-hands" techniques, as the samples were collected directly from the sampling ports or effluents. Pre-cleaned polyethylene bottles were used for the collection of these samples. Only the ambient and discharge waters collected for the translator study followed the collection procedures described for ambient waters. Unfiltered duplicate samples were collected from each site, and then they were bagged together. In the laboratory, the duplicates were manipulated in class-100 working areas. One duplicate was filtered with 45-mm, 0.45-µm pore-size, acid-cleaned, all-polypropylene syringe filters, using a peristaltic pump, Teflon® tubing, and low-diameter acid-rinsed Neoprene® tubing. Both samples were preserved with 2 mL of Q-HNO_3 per liter of sample. Copper concentrations were measured by dilution in 1N Q-HNO_3 and direct injection into a STGFAA spectrometer with Zeeman background correction. Blanks made up of 1N Q-HNO_3 and the SRM 1643d were used to evaluate the limit of detection, precision, and accuracy of the STGFAA analysis.

SHIPPING AND CHAIN OF CUSTODY

Samples were handled and shipped in accordance to the required holding times. The Chain of Custody followed in two main paths. For those samples that were analyzed at SSC San Diego, the Chain of Custody form includes the Field and Laboratory Notebooks of the personnel in control of the samples. For those samples that were analyzed in a laboratory other than SSC San Diego, a Chain of Custody form was submitted with the samples. The holding time for ambient waters is 6 months, but requires acidification in the minimal amount of time possible. Collected samples were air-shipped with personnel returning to SSC San Diego, and were acidified on the following working day after the sampling. Samples for WER were shipped on ice overnight to SSC San Diego. Upon arrival, samples were immediately evaluated for condition and water quality parameters, including arrival temperature. If necessary, samples were stored at approximately 4 °C upon arrival in the laboratory, but test set-up generally commenced immediately upon arrival. Holding time of samples for WER studies is limited to 96 hours following sample collection (USEPA, 2001). TSS samples were shipped on ice on a 3-day delivery service. These samples have a 7-day holding time.

TOC and DOC samples were frozen with dry ice immediately after collection and kept frozen until delivery to a commercial laboratory, Applied Marine Sciences, Inc. They were kept in a freezer and shipped with dry ice. A Chain of Custody form was submitted with the samples. Figure A-1 provides an example. As shown in this figure, samples for discharge characterization required filtration in the commercial laboratory.

5/22/2006	This is a list of samples collected as part of		FOURTH OFFICIAL SAMPLING EVENT 15-19 MAY 2006				at Pearl Harbor Naval Shipyard	
Type of Sample	**Sample ID**	**Sample info**	**Location**	**Date Collected**	**TOC**	**DOC**	**Requires filtration (0.45 µm)**	**NOTES**
AMBIENT	**NS**	**North Surface**	North	5/16/2006	×	×	**NO**	**Filtered in situ**
	ND	**North Depth**	North	5/16/2006	×	×	**NO**	**Filtered in situ**
	SS	**South Surface**	South	5/16/2006	×	×	**NO**	**Filtered in situ**
	SD	**South Depth**	South	5/16/2006	×	×	**NO**	**Filtered in situ**
	CS	**Central Surface**	Central	5/16/2006	×	×	**NO**	**Filtered in situ**
	CD	**Central Depth**	Central	5/16/2006	×	×	**NO**	**Filtered in situ**
	E	**East Loch**	East Loch	5/16/2006	×	×	**NO**	**Filtered in situ**
	M	**Middle Loch**	Middle Loch	5/17/2006	×	×	**NO**	**Filtered in situ**
	MNC	**Middle North Channel**	Middle North Channel	5/17/2006	×	×	**NO**	**Filtered in situ**
	W	**West Loch**	West Loch	5/17/2006	×	×	**NO**	**Filtered in situ**
	WC	**West Loch Channel**	West Loch Channel	5/17/2006	×	×	**NO**	**Filtered in situ**
TOXICITY TESTS	**GC**	**Granite Canyon**		5/17/2006	Not Collected	×	**NO**	**Filtered in situ**
	SIO	**Scripps**		1/26/2006	Not Collected	×	**NO**	**Filtered in situ**
EFFLUENT	**SWCDD1**	**SeaWater Cooling DD1**	Dry Dock 1	5/15/2006	×	×	**YES**	
	SWCDD1B	**SeaWater Cooling DD1**	Dry Dock 1	5/18/2006	×	×	**YES**	
	FMDD1	**Firemain (SeaWater Intake) DD1**	Dry Dock 1	5/15/2006	×	×	**YES**	
	FMDD1B	**Firemain (SeaWater Intake) DD1**	Dry Dock 1	5/18/2006	×	×	**YES**	
	EDD2	**Effluent DD2 (B) Round I**	Dry Dock 2	5/18/2006	×	×	**YES**	
	EDD2B	**Effluent DD2 (B) Round II**	Dry Dock 2	5/18/2006	×	×	**YES**	
	EDD4	**Effluent DD4**	Dry Dock 4	5/18/2006	×	×	**YES**	
	GWSDD4	**GroundWater Seepage DD4**	Dry Dock 4	5/18/2006	×	×	**YES**	

THE FOLLOWING SAMPLES WILL BE PROCESED AND WILL BE SENT TO APPLIED MARINE SCIENCES ASAP

TRANSLATOR								
	DD4N	**DD2-North**		5/23/2006	×	×	**NO**	**Filtered in lab**
	DD2C	**DD2-Central**		5/23/2006	×	×	**NO**	**Filtered in lab**
	DD4C	**DD4-Central**		5/23/2006	×	×	**NO**	**Filtered in lab**
	DD4S	**DD4- South**		5/23/2006	×	×	**NO**	**Filtered in lab**

Figure A-1. Chain of Custody form with list of samples.

ANALYTICAL METHODS

Copper concentrations

Copper concentrations were measured by STGFAA spectrometry in accordance with USEPA Method 7211 (USEPA, 1992). These measurements were done by injections in triplicate for each sample, with relative standard deviation in the absorbance measured of less than 10%. For analyses, the method of standard additions was used to correct for matrix interferences, with a minimal acceptable correlation coefficient (r) of 0.999 to ensure good precision. The SRM 1643d was included to check for the precision, bias, and accuracy of the analysis. This SRM was analyzed every five samples, and the analysis was accepted only when the recovery for this SRM is within ±15% of the certified value. 1N Q-HNO_3 blanks were also analyzed every five samples to estimate the method detection limit. At least one sample was analyzed in duplicate for every STGFAA run to provide information on the precision of the analysis. The procedure for each batch of samples analyzed included the following:

- Rod blank, which is the copper concentration in the graphite tube and platform themselves.
- Standard addition with at least three standards in the first sample to be analyzed, with a correlation coefficient (r) of 0.999 or better.
- Measurement on the other samples in the batch.
  - ♦ Including a SRM 1643d and a 1N Q-HNO_3 blank every five samples.
  - ♦ Including analysis of a sample and of the same sample spiked with standard.
- Standard addition with at least three standards in the same first sample, with a correlation coefficient (r) of 0.999 or better.
- Calculate the slope of both Standard Additions and calculate the slope for each sample, assuming a linear change in slope.
- Use this calculated slope and dilution for calculation of the measured copper concentration.

Total Suspended Solids (TSS) in Seawater

The sample analysis for TSS follows the standard protocols developed by the University of New Hampshire (University of New Hampshire, 1992). In summary, the samples are filtered using pre-dried /pre-weighed glass fiber filters (GFC) with 1.2-mm nominal pore retention. The filters with suspended solids are dried in an oven (preset at 90 to 120 ºC) for 24 hours and weighed again. The TSS concentration is determined by calculating the difference between the filter weights (before/after filtration) and divided by the total volume filtered.

The actual procedure is as follows. A 25-mm glass microfiber fiber filter (wrapped in aluminum foil) is initially pre-dried in an oven set at 100 ºC for 24 hours. The filter is cooled in a dessicator for 5 minutes. Using an analytical balance, the initial pre-dried filter weight (W_i) is recorded to the nearest tenth of a milligram, and the filter is transferred into an aluminum weighing dish. Before placement of the filter, the filtration apparatus (i.e., funnel/base) is rinsed with deionized water.

A volume (V_f) of approximately 200 to 600 ml of sample seawater is filtered and recorded. During filtration, the container and funnel/base are rinsed, with the rinsate being filtered through to collect any accumulated suspension. Using forceps, the filter is removed and placed into the weighing dish (with the top covered with aluminum foil) and then dried again overnight. The same balance is used to weigh the final solids filter (W_f). The TSS in milligrams per liter of water is calculated by subtracting W_i from W_f and dividing this weight (W_{tss}) by V_f , as indicated in the following equations.

$$W_{tss} = W_f - W_i$$

$$TSS = \frac{W_{tss}}{V_f},$$

where

TSS is the Total Suspended Solids concentration (mg/L)
W_{tss} is the weight of suspended solids (mg)
V_f is the volume filtered (L).

Total and Dissolved Organic Carbon.

These parameters were measured at a commercial laboratory (Applied Marine Sciences, Inc., following USEPA method 415.1 (USEPA, 1974). This method is for the measurement of organic carbon following a combustion or oxidation. In the treatment the organic carbon is converted to carbon dioxide (CO_2) by either catalytic combustion or wet chemical oxidation. The CO_2 can then be measured directly by an infrared detector, or it can be converted to methane (CH_4) and measured by a flame ionization detector. The amount of CO_2 or CH_4 is directly proportional to the concentration of organic carbon material in the sample.

Ancillary Parameters

Ancillary parameters, including salinity, pH, temperature, conductivity, and dissolved oxygen were measured in situ with standard portable instruments.[†]

APPENIDX A REFERENCES

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APPENDIX B

DATA QUALITY ASSURANCE/QUALITY CONTROL PLAN

PURPOSE AND SCOPE

The purpose of the Quality Assurance/Quality Control (QA/QC) Plan is to document the results of the technical planning process, providing a clear, concise, and complete plan for the environmental data operation and its quality objectives and identifying key project personnel (USEPA, 2002). This plan is designed to maintain an adequate quantity and quality of data for the Copper Water Compliance Studies at Pearl Harbor naval Shipyard and Intermediate Maintenance Facility. Careful adherence to these procedures ensures that data generated from the study meet the desired performance objectives and yield appropriate analytical results.

QUALITY ASSURANCE RESPONSIBILITIES

The team performing the study is responsible for ensuring that the QA/QC Plan is implemented as written. The members of the team are part of SSC San Diego. The QA officers were Dr. Ignacio Rivera-Duarte for measurements of copper concentrations, Mr. Gunther Rosen for toxicity testing, and Mr. Joel Guerrero for TSS measurements, who coordinated all QA activities, monitored methods and records throughout the study and data analysis, and reviewed the data reduction and validation.

DATA QUALITY PARAMETERS

An extensive suite of parameters is required to develop WER, translator, and discharge characterization. These parameters were measured from samples collected through the Copper Water Compliance studies. The quality of the data generated for these measurements is affected by the sampling and analytical techniques used; therefore, state-of-the-art trace metal clean techniques were used in sampling and analysis. Sampling was done following USEPA Method 1669 (USEPA, 1996) on Sampling Ambient Water for Trace Metals, as the use of these techniques will ensure the representativeness of the samples. Furthermore, the use of trace metal clean techniques and standard reference materials (SRMs) in the analysis of the samples will provide information about the quality parameters of the data. These data quality parameters are the precision, bias, accuracy, representativeness, comparability, completeness, and sensitivity, and are defined and measured as follows (USEPA, 2002):

Precision is the measurement of agreement among repeated measurements of the same property under identical or substantially similar conditions. It is calculated as the range or the standard deviation. But, it may also be expressed as a percentage of the mean of the measurements, such as relative range, relative standard deviation, or coefficient of variation (CV). Precision is quantified by using the same analytical instrument to make repeated analyses on the same sample, or by splitting a sample in the field and submitting both for sample handling, preservation and storage, and analytical measurements.

Bias is the systematic or persistent distortion of a measurement process that causes errors in one direction. This distortion is quantified with the use of SRMs, or by analysis of spiked matrix samples. SRM 1643d was used to check for bias in the STGFAA analysis.

Accuracy is a measure of the overall agreement of a measurement to a known value and includes a combination of random error (precision) and systematic error (bias) components of sampling and analytical operations. Accuracy is quantified with SRMs, or by repetitive analysis of spiked samples with known concentration. It is usually expressed as percent recovery or as a percent bias. In the case of the STGFAA analyses, the SRM 1643d was used to check for accuracy and is reported as percent recovery.

Representativeness is a qualitative term that expresses "the degree to which data accurately and precisely represent a characteristic of a population, parameter variations at a sampling point, a process condition, or an environmental condition". Representativeness is evaluated by the consistency of the data in comparison with historical data for locations with similar characteristics.

Comparability is a qualitative term that expresses the measure of confidence that one data set can be compared to another and can be combined for the decision(s) to be made. Comparabilty is qualified by the similarity of sampling collection and handling methods, sample preparation and analytical procedures, holding times, stability issues, and QA protocols.

Completeness is a measure of the amount of valid data that needs to be obtained from a measurement system. This task is accomplished by comparing the number of valid measurements completed (samples collected or samples analyzed) with those established by the project's quality criteria.

Sensitivity is the capability of a method or instrument to discriminate between measurement responses representing different levels of the variable of interest. Sensitivity is quantified as the minimum concentration that can be measured by a method (method detection limit), by an instrument (instrument detection limit), or by a laboratory (quantization limit).

CALIBRATION PROCEDURES, QUALITY CONTROL CHECKS, AND CORRECTIVE ACTION

Measurements of the copper concentrations in effluents were done by direct injection of diluted samples into a STGFAA spectrometer in accordance with USEPA Method 7211 (USEPA, 1992). These measurements were done by injections in triplicate for each sample, with relative standard deviation in the absorbance measured of less than 10%. Analyses were done with the method of standard additions to correct for matrix interferences, with a minimal acceptable correlation coefficient (r) of 0.999 to ensure good precision. The SRM 1643d was included to check for the precision, bias, and accuracy of the analysis. This SRM was analyzed every five samples, and the analysis was accepted only when the recovery for this SRM was within ±15% of the certified value. 1N Q-HNO_3 was also analyzed every five samples for the estimation of the method detection limit. At least one sample was analyzed in duplicate for every STGFAA run to provide information on the precision of the analysis.

Calculation of Data Quality Indicators

The quality of the measurements required for the Copper Water Compliance studies were evaluated in accordance with accepted U.S. EPA methodology (USEPA, 2000). All of the data quality parameters are based in commonly used statistical calculations, including determining the mean value, the standard deviation, and the coefficient of variation. The calculation of these parameters is performed in accordance with the following guidelines (USEPA, 2000).

The sample mean or average ($\bar{X}$) is calculated as follows:

$$\bar{X} = \frac{1}{n} \sum_{i=1}^{n} X_i$$

The sample variance (s^2) is required for the calculation of the standard deviation (s), and is calculated in accordance with this equation:

$$s^2 = \frac{\sum_{i=1}^{n} X_i^2 - \frac{1}{n}\left(\sum_{i=1}^{n} X_i\right)^2}{n-1}$$

The sample standard deviation (s) is used as a measure of the precision of the measurements, and is calculated from the variance as follows:

$$s = \sqrt{s^2}$$

The standard deviation of duplicate samples or duplicate STGFAA analysis of the same sample will be provided as evidence of the precision of the analysis. The standard deviation of replicate blanks made up of 1N Q-HNO_3 in 18 MΩ/cm is used to estimate the sensitivity of the method, as the method detection limit and the quantization limit. The method detection limit is calculated as three times the standard deviation of the blanks, and the quantization limit is defined as 10 times the standard deviation of the blanks.

Another measure of the precision of the analysis is the coefficient of variation (CV), which is the ratio of the standard deviation (s) to the mean, and is calculated as follows:

$$CV = s / \bar{X} = \frac{\left[\frac{1}{n-1} \sum_{i=1}^{n} (X_i - \bar{X})^2 \right]^{1/2}}{\frac{1}{n} \sum_{i=1}^{n} X_i}$$

In the method of standard additions for STGFAA measurements, establishing the response of the instrument to additions of the analyte to the sample is critical, and is accomplished with the Pearson's correlation coefficient (r), which is calculated as follows:

$$r = \frac{\sum_{i=1}^{n} X_i Y_i - \frac{\sum_{i=1}^{n} X_i \sum_{i=1}^{n} Y_i}{n}}{\left[\left[\sum_{i=1}^{n} X_i^2 - \frac{(\sum_{i=1}^{n} X_i)^2}{n} \right] \left[\sum_{i=1}^{n} Y_i^2 - \frac{(\sum_{i=1}^{n} Y_i)^2}{n} \right] \right]^{1/2}}$$

Bias and accuracy of the analysis was measured as percent recovery of SRM 1643d. This SRM was analyzed every five samples on each of the STGFAA runs, and the mean value measured was compared to the reported copper concentration of 20.5 ±3.8 µg/L. The accuracy of the analysis was assessed by ensuring that the measured mean recovery is within 15% of the reported concentration. The bias of the measurement is assessed by ensuring that all of the measurements are within the same 15% recovery limits.

E.8. ISO 14001

The Environmental Management System (EMS) implemented at SSC San Diego was followed throughout the study. This EMS complies with Navy EMS requirements, which follow the ISO 14001 International Standard. The following items are the five key elements on this EMS:

1. Environmental Policy at SSC San Diego:
    1.1. Comply with all applicable environmental regulations.
    1.2. Minimize environmental impacts by preventing or reducing pollution.
    1.3. Strive to continually improve our environmental performance.

2. Impact on the environment
    2.1. Some of the ways our processes/activities impact the environment are as follows:
        2.1.1. Computers and lights use up energy.
        2.1.2. Waste paper not recycled can fill up our landfills.
        2.1.3. Processes (like painting, cleaning and vehicle maintenance) use hazardous materials (HM) that create air emissions, produce wastewater or generate hazardous waste (HW).

3. Pollution Prevention (P2) Plan to reduce environmental impacts.
    3.1. Analyzes processes for potential reductions in HM usage and/or HW generation.
    3.2. Identifies P2 solutions for these processes.
    3.3. Assesses the feasibility of implementing these solutions.
    3.4. Implements the solutions.

4. Specific objectives and targets for significant minimization of SSC San Diego environmental impacts:
    4.1. Reduce solid waste generation by 25% by December 2008 by identifying recycling opportunities and increasing two-sided printing.
    4.2. Increase procurement of paper with 100% recycled content with 100% compliance by December 2006.
    4.3. Reduce overall energy usage by 35% by December 2010 by turning off lights and equipment when not in use and participating in Facilities Office projects to install more energy-efficient lighting.

5. Procedures for dealing with emergency situations
    5.1. If there is an emergency beyond your control:
    5.1.1. Call 9911 (in rapid succession with no pause between the 9s) from a safe location. This procedure will connect you with the Federal Fire Department.
    5.1.2. If on a cell phone, call 911. When the person answers, inform them you are calling from a Navy facility. They will then connect you with the Federal Fire Department.

While these elements are very general and apply for all the personnel at SSC San Diego, the elements that specifically affect the study were strictly followed. These elements are those regarding the use and disposal of hazardous materials and the safety of our personnel.

Data Format

Most of the measured data **are** stored as tables. However, scatter plots or any other form of representation or analysis are used as required. The results from the study are presented as tables, scatter plots, time period plots, **or** contour plots/maps. These formats are used as required for the analysis of the results, and validation of the data.

Data Storage and Archiving Procedures

All final data are stored electronically. The storage media includes hard-disk memory, external hard disk, CD-ROM, and flashpoint memory. A folder as main central information depository is at the share-system at SSC San Diego. In contrast to the final data, the raw data will be kept in laboratory notebooks, which will include notes for each specific experiment, and for any problem identified in the experiment.

Quality Assurance and Quality Control for Ambient Samples

QA/QC for ambient samples was followed for collection and analytical procedures. QA/QC for sampling included Field and Bottle Blanks. The average concentration for the field blanks was

0.070 ± 0.076 µg/L (n = 4), and one bottle blank was measured with a copper concentration of 0.011 µg/L. The average field blank copper concentration is 13% (range 5 to 53%) of the average dissolved concentration and 10% (range 4 to 39%) of the average total copper concentration measured in ambient samples.

The analytical QA/QC included using SRM CASS4 and duplicate extractions for the liquid/liquid preconcentration step, and SRM 1643d, 1N Q-HNO_3 blanks, and spiked samples for STGFAA analysis. An average recovery of 93.9 ±2.3 % (n = 4) was measured for the certified copper concentration of 0.592 ±0.055 µg/L for CASS4, which indicates that the copper concentrations measured on the preconcentrated samples are, in average, 93.9% of the actual value. Replicate extractions are used to evaluate the precision of the extraction, and an average Relative Standard Deviation (RSD) of 3.7 ±3.6 % (n = 5) was calculated for them, that is, the copper concentration measured in preconcentrated samples had an average precision of 3.7%.

Measurement of copper concentrations in preconcentrated ambient samples by STGFAA included the analysis of SRM 1643d and 1N Q-HNO_3 blanks every five samples, and spiking of a sample. An average recovery of 94.7 ±4.2 % (n = 44) was calculated for the analysis of SRM 1643d, which is within the ±15% (85 to 115%) recovery required for QA/QC. The measured concentrations in average are 94.7% of the actual value. The average concentration for the 1N Q-HNO_3 blanks was 0.045 ±0.063 µg/L (n=61), with a Method Detection Limit (MDL) of 0.188 µg/L calculated as three standard deviations of the blanks. Concentrations measured after liquid/liquid preconcentration do include a preconcentration factor after the STGFAA analysis for actual calculation. Most of the preconcentrated samples, except for the blanks, require a dilution to bring the copper concentration into the linear range of the STGFAA. Recovery for spiked samples had an average of 104.9 ±5.1% (n = 6), also within the range of 15% required by QA/QC.

Quality Assurance and Quality Control for Translator Samples

Translator studies require collecting ambient and effluent waters, and the mixtures of these waters in some ratio. These requirements impose QA/QC for collection and analytical procedures. QA/QC for sampling includes the use of field and bottle blanks. The average concentration for the field blanks was 0.070 ±0.076 µg/L (n = 4), and one bottle blank was measured with a copper concentration of 0.011 µg/L. The average field blank copper concentration is 13% (range, 5 to 53%) of the average dissolved concentration, and 10% (range, 4 to 39%) of the average total copper concentration measured in ambient samples.

Analysis of samples for translator studies was done in two different paths. For samples with copper concentration at the ambient level, first a liquid-liquid preconcentration was used, with subsequent copper concentration measurement by STGFAA in the preconcentrates. For samples with copper concentrations above those at ambient levels (≥2 µg/L), a dilution with 1N Q-HNO_3 was first done, and then the copper concentration in the diluted sample was measured by STGFAA. A corresponding analytical QA/QC is then applied for each step.

The analytical QA/QC for the liquid/liquid preconcentration step included the use of SRM CASS4 and duplicate extractions. An average recovery of 93.9 ± 2.3 % (n=4) was measured for the certified copper concentration of 0.592 ± 0.055 µg/L for CASS4, this indicates that the copper concentrations measured on the preconcentrated samples are, in average, 93.9% of the actual value. Replicate extractions are used to evaluate the precision of the extraction, and an average RSD of 3.7 ±3.6% (n=5) was calculated for them, that is, the copper concentration measured in preconcentrated samples had an average precision of 3.7%.

The QA/QC for the analysis by STGFAA of the preconcentrated samples included the use SRM 1643d, 1N Q-HNO_3 Blanks, and spiked samples. For the STGFAA analysis of the preconcentrated samples an average recovery of 94.7 ± 4.2 % (n= 44) was calculated for SRM 1643d. This is within the ±15% (85 to 115%) recovery required for QA/QC, and indicates that the measured concentrations in average are 94.7% of the actual value. The average concentration for the 1N Q-HNO_3 Blanks was 0.045 ± 0.063 µg/L (n=61), with a MDL of 0.188 µg/L calculated as three standard deviations of the blanks. It must be mentioned that concentrations measured after liquid-liquid preconcentration do include a preconcentration factor after the STGFAA analysis for actual calculation, and that most of the preconcentrated samples, but the blanks, require a dilution in order to bring the copper concentration into the linear range of the STGFAA. Recovery for spiked samples had an average of 104.9 ± 5.1 % (n=6), also within the range of 15% required by QA/QC.

For the Translator samples with relative large copper concentration that were diluted in 1N Q-HNO_3 and injected directly into the STGFAA for copper measurement, the QA/QC also included the use SRM 1643d, 1N Q-HNO_3 Blanks, and spiked samples. For these samples an average recovery of 103.1 ± 7.2 % (n= 18) was calculated for the analysis of SRM 1643d. This is within the ±15% (85 to 115%) recovery required for QA/QC, and indicates that the measured concentrations in average are 103.1% of the actual value. The average concentration for the 1N Q-HNO_3 Blanks was 0.006 ± 0.076 µg/L (n=24), with a MDL of 0.227 µg/L calculated as three standard deviations of the blanks. Recovery for spiked samples had an average of 108 ±9.7% (n=3), also within the range of 15% required by QA/QC.

Quality Assurance and Quality Control for Discharge Characterization Samples

While most of the samples for the Discharge Characterization study have copper concentrations in the few µg/Ls range, some of them had concentrations at the ambient level of less than 1 µg/L. Some of these samples were collected simultaneously, using the trace metal clean techniques used for ambient samples (i.e., channel that feeds seawater to the seawater intake/firemain system). These characteristics impose the use of QA/QC for collection and analytical procedures. QA/QC for sampling includes the use of field and bottle blanks. The average concentration for the Field Blanks was 0.070 ±0.076 µg/L (n = 4), and one bottle blank was measured with a copper concentration of 0.011 µg/L. The average field blank copper concentration is 13% (range 5 to 53%) of the average dissolved concentration, and 10% (range 4 to 39%) of the average total copper concentration measured in ambient samples.

Depending on the concentration in the Discharge Characterization sample, its analysis was done in two different paths. For samples with copper concentration at the ambient level, a liquid/liquid preconcentration was first used, with subsequent copper concentration measurement by STGFAA in the preconcentrates. For samples with copper concentrations above those at ambient levels (≥2 µg/L), a dilution with 1N Q-HNO_3 was first done, and then the copper concentration in the diluted sample was measured by STGFAA. A corresponding analytical QA/QC was then applied for each step.

The analytical QA/QC for the liquid/liquid preconcentration step included using SRM CASS4 and duplicate extractions. An average recovery of 93.9 ±2.3% (n = 4) was measured for the certified copper concentration of 0.592 ±0.055 µg/L for CASS4, which indicates that the copper concentrations measured on the preconcentrated samples are, in average, 93.9% of the actual value. Replicate extractions are used to evaluate the precision of the extraction, and an average RSD of 3.7 ±3.6% (n = 5) was calculated for them. The copper concentration measured in preconcentrated samples had an average precision of 3.7%.

The QA/QC for the analysis by STGFAA of the preconcentrated samples included using SRM 1643d, 1N Q-HNO_3 blanks, and spiked samples. For the STGFAA analysis of the preconcentrated samples an average recovery of 94.7 ± 4.2 % (n = 44) was calculated for SRM 1643d. This calculation is within the ±15% (85 to 115%) recovery required for QA/QC, and indicates that the measured concentrations, in average, are 94.7% of the actual value. The average concentration for the 1N Q-HNO_3 blanks was 0.045 ±0.063 µg/L (n = 61), with a MDL of 0.188 µg/L calculated as three standard deviations of the blanks. It must be mentioned that concentrations measured after liquid/liquid preconcentration do include a preconcentration factor after the STGFAA analysis for actual calculation, and that most of the preconcentrated samples, but the blanks, require a dilution to bring the copper concentration into the linear range of the STGFAA. Recovery for spiked samples had an average of 104.9 ±5.1 % (n = 6), also within the range of 15% required by QA/QC.

The QA/QC for STGFAA analysis of 1N Q-HNO_3-diluted Discharge Characterization samples also included the use SRM 1643d, 1N Q-HNO_3 blanks, and spiked samples. An average recovery of 104.0 ±6.5% (n = 40) was calculated for the analysis of SRM 1643d. This is calculation is within the ±15% (85 to 115%) recovery required for QA/QC, and indicates that the measured concentrations in average are 104.0% of the actual value. The average concentration for the 1N Q-HNO_3 blanks was 0.027 ±0.043 µg/L (n =56), with a MDL of 0.129 µg/L calculated as three standard deviations of the blanks. Recovery for spiked samples had an average of 108.4 ±8.1% (n = 5), also within the range of 15% required by QA/QC.

Quality Assurance and Quality Control for WER Samples

WER studies include the collection of ambient waters, the set-up of batches of these ambient waters spiked with different levels of copper concentration, the addition of larva and the evaluation of the toxic concentration to that larva. Therefore, while the initial concentration in the samples is at ambient level, the copper concentration in the spiked aliquots includes a fairly large range from less than 1 up to 50 µg/L. The use of ambient waters imposes a QA/QC for sampling and for analysis of those waters. In this case ambient waters were first preconcentrated and the copper concentration was measured by STGFAA. In the case of the spiked aliquots, they were diluted with 1N Q-HNO_3 and then directly injected into a STGFAA for measurement. Therefore, QA/QC for each of these steps is required.

QA/QC for sampling includes the use of field and bottle blanks. The average concentration for the field blanks was 0.070 ±0.076 µg/L (n = 4), and one bottle blank was measured with a copper concentration of 0.011 µg/L. The average field blank copper concentration is 13% (range 5 to 53%) of the average dissolved concentration, and 10% (range 4 to 39%) of the average total copper concentration measured in ambient samples.

The analytical QA/QC for the liquid/liquid preconcentration step included using SRM CASS4 and duplicate extractions. An average recovery of 93.9 ±2.3 % (n = 4) was measured for the certified copper concentration of 0.592 ±0.055 µg/L for CASS4, which indicates that the copper concentrations measured on the preconcentrated samples are, in average, 93.9% of the actual value. Replicate extractions are used to evaluate the precision of the extraction, and an average RSD of 3.7 ±3.6% (n = 5) was calculated for them. The copper concentration measured in preconcentrated samples had an average precision of 3.7%.

The QA/QC for the analysis by STGFAA of the preconcentrated samples included SRM 1643d, 1N Q-HNO_3 blanks, and spiked samples. For the STGFAA analysis of the preconcentrated samples, an average recovery of 94.7 ±4.2 % (n = 44) was calculated for SRM 1643d and is within the ±15% (85 to 115%) recovery required for QA/QC. The measured concentrations, in average, are 94.7% of the actual value. The average concentration for the 1N Q-HNO_3 blanks was 0.045 ±0.063 µg/L (n = 61), with an MDL of 0.188 µg/L calculated as three standard deviations of the blanks. Concentrations measured after liquid/liquid preconcentration do include a preconcentration factor after the STGFAA analysis for actual calculation, and most of the preconcentrated samples, except for the blanks, require a dilution to bring the copper concentration into the linear range of the STGFAA. Recovery for spiked samples had an average of 104.9 ±5.1% (n = 6), also within the range of 15% required by QA/QC.

The QA/QC for STGFAA analysis of 1N Q-HNO_3-diluted WER samples diluted also included using SRM 1643d, 1N Q-HNO_3 blanks, and spiked samples. An average recovery of 101.0 ±7.4% (n = 223) was calculated for the analysis of SRM 1643d. This value is within the ±15% (85 to 115%) recovery required for QA/QC and indicates that the measured concentrations, in average, are 101.0% of the actual value. The average concentration for the 1N Q-HNO_3 blanks was 0.014 ±0.044 µg/L (n = 316), with a MDL of 0.133 µg/L calculated as three standard deviations of the blanks. Recovery for spiked samples had an average of 102 ±7.4% (n = 39), also within the range of 15% required by QA/QC.

APPENDIX B REFERENCES

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APPENDIX C

RECALCULATION STUDY: NATIONAL COPPER TOXICITY DATASET FOR SEAWATER (REPRODUCED FROM USEPA 1995A)

National Copper Toxicity Dataset for Saltwater (from USEPA 1995)

Values based on dissolved copper (when dissolved data not available, a 0.83 or 0.90 conversion factor was used by EPA, depending on availability of measured or nominal values, respectively)

Bold indicate species are present in Pearl Harbor according to Pearl Harbor Legacy Database

Common Name	Genus	Species	Species Mean Acute Value (ug/L)	Genus Mean Acute Value (ug/L)
Topsmelt	Atherinops	affinis	218.7	218.7
Tidewater silverside	Menidia	peninsulae	126.0	116.3
Atlantic silverside	Menidia	menidia	112.5	116.3
Inland silverside	Menidia	beryllina	111.1	116.3
Killifish	Fundulus	heteroclitus	1,391	1,391
Sheepshead minnow	Cyprinodon	variegatus	305.4	305.4
Florida pompano	Trachinotus	carolinus	370.5	370.5
Spot	Leiostomus	xanthurus	252.0	252.0
Winter flounder	Pseudopleuronectes	americanus	107.0	107.0
Summer flounder	Paralichthys	dentatus	11.56	11.56
Soft-shell clam	Mya	arenaria	35.10	35.10
Eastern oyster	**Crassostrea**	**virginica**	**25.67**	**21.40**
Pacific oyster	**Crassostrea**	**gigas**	**17.84**	**21.40**
Common rangia	Rangia	cuneata	6,925	6,925
Coot clam	Mulinia	lateralis	17.70	17.70
Blue mussel	Mytilus	edulis	9.63	9.63
Red abalone	Haliotis	rufescens	77.47	59.04
Black abalone	Haliotis	cracherodii	45.00	59.04
Green crab	Carcinus	maenas	540.0	540.0
Dungeness crab	Cancer	magister	44.10	44.10
American lobster	Homarus	americanus	62.35	62.35
Mysid	Mysidopsis	bahia	157.0	135.5
Mysid	Mysidopsis	bigelowi	117.0	135.5
Copepod	Acartia	clausi	46.80	35.97
Copepod	Acartia	tonsa	27.65	35.97
Copepod	Eurytemora	affinis	473.40	473.40
Copepod	Pseudodiaptomus	coronatus	124.2	124.2
Copepod	Tigriopus	californicus	212.40	212.40
Polychaete worm	**Neanthes**	**arenaceodentata**	**150.6**	**150.6**
Polychaete worm	Phyllodoce (Anaitides)	maculata	108.0	108.0
Polychaete worm	Nereis	virens	>206.7	>260.1
Polychaete worm	Nereis	diversicolor	327.4	>260.1
Sea urchin	Arbacia	punctulata	21.4	21.4

APPENDIX D

RECALCULATION STUDY: ADJUSTED COPPER TOXICITY DATASET (INCLUDES CORRECTIONS AND ADDITIONS) USED FOR THE DELETION PROCESS

Adjusted Copper Toxicity Dataset Used for Deletion Process (Page 1 of 2)
(Includes Corrections and Additions)

Bold indicate species are present in Pearl Harbor according to Pearl Harbor Legacy Database
* Denotes species was added due to presence in Pearl Harbor, economic/ecological importance, and availability of relevant toxicity data.

Common Name	Genus	Species	Species Mean Acute Value (ug/L)	Genus Mean Acute Value (ug/L)	Family	Order	Class	Phylum
Topsmelt	Atherinops	affinis	218.7	218.7	Atherinidae	Atheriniformes	Actinopterygii	Chordata
Tidewater silverside	Menidia	peninsulae	126.0	116.3	Atherinidae	Atheriniformes	Actinopterygii	Chordata
Atlantic silverside	Menidia	menidia	112.5	116.3	Atherinidae	Atheriniformes	Actinopterygii	Chordata
Inland silverside	Menidia	beryllina	111.1	116.3	Atherinidae	Atheriniformes	Actinopterygii	Chordata
Killifish	Fundulus	heteroclitus	1,391	1,391	Fundulidae	Cyprinodontiformes	Actinopterygii	Chordata
Sheepshead minnow	Cyprinodon	variegatus	305.4	305.4	Cyprinodontidae	Cyprinodontiformes	Actinopterygii	Chordata
Florida pompano	Trachinotus	carolinus	370.5	370.5	Carangidae	Perciformes	Actinopterygii	Chordata
Spot	Leiostomus	xanthurus	252.0	252.0	Sciaenidae	Perciformes	Actinopterygii	Chordata
Mozambique Tilapia*	**Oreochromis**	**mossambicus**	**2,237.0**	**2,237.0**	**Cichlidae**	**Perciformes**	**Actinopterygii**	**Chordata**
Winter flounder	Pseudopleuronectes	americanus	107.0	107.0	Pleuronectidae	Pleuronectiformes	Actinopterygii	Chordata
Summer flounder	Paralichthys	dentatus	11.56	11.56	Paralichthyidae	Pleuronectiformes	Actinopterygii	Chordata
Soft-shell clam	Mya	arenaria	35.10	35.10	Myidae	Myoida	Bivalvia	Mollusca
Eastern oyster	**Crassostrea**	**virginica**	**29.18**	**22.82**	**Ostreidae**	**Ostreoida**	**Bivalvia**	**Mollusca**
Pacific oyster	**Crassostrea**	**gigas**	**17.84**	**22.82**	**Ostreidae**	**Ostreoida**	**Bivalvia**	**Mollusca**
Common rangia	Rangia	cuneata	6,925	6,925	Mactridae	Veneroida	Bivalvia	Mollusca
Coot clam	Mulinia	lateralis	17.70	17.70	Mactridae	Veneroida	Bivalvia	Mollusca
Blue mussel	Mytilus	edulis	9.63	9.63	Mytilidae	Mytiloida	Bivalvia	Mollusca
Red abalone	Haliotis	rufescens	77.47	59.04	Haliotidae	Archaeogastropoda	Gastropoda	Mollusca
Black abalone	Haliotis	cracherodii	45.00	59.04	Haliotidae	Archaeogastropoda	Gastropoda	Mollusca
Green crab	Carcinus	maenas	540.0	540.0	Portunidae	Decapoda	Malacostraca	Arthropoda
Dungeness crab	Cancer	magister	44.10	44.10	Cancridae	Decapoda	Malacostraca	Arthropoda
American lobster	Homarus	americanus	62.35	62.35	Nephropidae	Decapoda	Malacostraca	Arthropoda
Mysid	Mysidopsis	bahia	157.0	135.5	Mysidae	Mysida	Malacostraca	Arthropoda
Mysid	Mysidopsis	bigelowi	117.0	135.5	Mysidae	Mysida	Malacostraca	Arthropoda
Copepod	Acartia	clausi	46.80	35.97	Acartidae	Calanoida	Maxillipoda	Arthropoda
Copepod	Acartia	tonsa	27.65	35.97	Acartidae	Calanoida	Maxillipoda	Arthropoda
Copepod	Eurytemora	affinis	473.40	473.40	Temoridae	Calanoida	Maxillipoda	Arthropoda
Copepod	Pseudodiaptomus	coronatus	124.2	124.2	Pseudodiaptomidae	Calanoida	Maxillipoda	Arthropoda
Copepod	Tigriopus	californicus	212.40	212.40	Harpacticidae	Harpacticoida	Maxillipoda	Arthropoda
Polychaete worm	**Neanthes**	**arenaceodentata**	**150.6**	**150.6**	**Nereididae**	**Aciculata**	**Polychaeta**	**Annelida**
Polychaete worm	Phyllodoce (Anaitides)	maculata	108.0	108.0	Phyllodocidae	Aciculata	Polychaeta	Annelida
Polychaete worm	Nereis	virens	>206.7	>260.1	Nereididae	Aciculata	Polychaeta	Annelida
Polychaete worm	Nereis	diversicolor	327.4	>260.1	Nereididae	Aciculata	Polychaeta	Annelida
Sea urchin	Arbacia	punctulata	21.40	21.40	Arbaciidae	Arbacioida	Echinoidea	Echinodermata
Hawaiian Collector urchin*	**Tripneustes**	**gratilla**	**14.06**	**14.06**	**Temnopleuridae**	**Temnopleurida**	**Echinoidea**	**Echinodermata**
Lace Coral*	**Pocillopora**	**damicornis**	**56.70**	**56.70**	**Pocilloporidae**	**Scleractinia**	**Anthozoa**	**Cnidaria**

Adjusted Copper Toxicity Dataset for Use in Deletion Process (Page 2 of 2)
(Includes Corrections and Additions)

Genus	Species	Species Present?	Genera Occur at site?	Other Species in Genera present but NOT in database?	Family Present?	Other Genera in Family present but NOT in database?	Order Present?	Database has Species in Same Order?	Class Present?	Database has circled Species in same Class?	Phylum Present?	Database has Species in same Phylum?	Action
Atherinops	affinis	N	N	N	N	N	N	N	Y	**N**	Y	Y	Retain
Menidia	peninsulae	N	N		N		N		Y	**N**			Retain
Menidia	menidia	N	N		N		N		Y	**N**			Retain
Menidia	beryllina	N	N		N		N		Y	**N**			Retain
Fundulus	heteroclitus	N	Y	**Y**	Y		Y		Y				Retain
Cyprinodon	variegatus	N	N		Y	**Y**	Y		Y				Retain
Trachinotus	carolinus	N	N		Y	**Y**	Y		Y				Retain
Leiostomus	xanthurus	N	N		N		Y	**N**	Y				Retain
Oreochromis	**mossambicus**	**Y**	**Y**		**Y**		**Y**		**Y**				Retain
Pseudopleuronectes	americanus	N	N		N		Y	**N**	Y				Retain
Paralichthys	dentatus	N	N		N		Y	**Y**	Y	Y	Y	Y	Delete
Mya	arenaria	N	N		N		Y	**N**	Y				Retain
Crassostrea	**virginica**	**Y**	**Y**		**Y**		**Y**		**Y**				Retain
Crassostrea	**gigas**	**Y**	**Y**		**Y**		**Y**		**Y**				Retain
Rangia	cuneata	N	N		N		Y	**N**	Y				Retain
Mulinia	lateralis	N	N		N		Y	**N**	Y				Retain
Mytilus	edulis	N	N		N?	**N**	N?		Y	Y	Y	Y	Delete
Haliotis	rufescens	N	N		N		Y	**N**	Y				Retain
Haliotis	cracherodii	N	N		N		Y	**N**	Y				Retain
Carcinus	maenas	N	N		Y	**N**	Y		Y				Retain
Cancer	magister	N	N		N		Y	**N**	Y				Retain
Homarus	americanus	N	N		N		Y	**N**	Y				Retain
Mysidopsis	bahia	N	N		N?		Y	**N**	Y				Retain
Mysidopsis	bigelowi	N	N		N?		Y	**N**	Y				Retain
Acartia	clausi	N	N		N?		N?		Y	**N**			Retain
Acartia	tonsa	N	N		N?		N?		Y	**N**			Retain
Eurytemora	affinis	N	N		N?		N?		Y	**N**			Retain
Pseudodiaptomus	coronatus	N	N		N?		N?		Y	**N**			Retain
Tigriopus	californicus	N	N		N		N		Y	**N**			Retain
Neanthes	**arenaceodentata**	**Y**	**Y**		**Y**		**Y**		**Y**				Retain
Phyllodoce (Anaitides)	maculata	N?	**Y**	**Y**	Y		Y		Y				Retain
Nereis	virens	N	Y	**Y**	Y		Y		Y				Retain
Nereis	diversicolor	N	Y	**Y**	Y		Y		Y				Retain
Arbacia	punctulata	N	N		N		N		Y	**N**			Retain
Tripneustes	**gratilla**	**Y**	**Y**		**Y**		**Y**		**Y**				Retain
Pocillopora	**damicornis**	**Y**	**Y**		**Y**		**Y**		**Y**				Retain

APPENDIX E

WER: SITE WATER HANDLING SUMMARY

Table E-1. Sample handling details

Sampling Date	Sample ID	Sampling Time	Received at SSC-SD Date	Time	Temp (°C)	pH (SU)	D.O. (mg/L)	Salinity (ppt)	Test Initiation Date	Time 1° Sp.	Time 2° Sp.	Elapsed Time (hrs) Collection to Testing 1° Sp.	2° Sp.
3/15/2005	N	1221	3/16/2005	1230	6.8	8.17	7.6	34.3	3/16/2005	1605	-	27.7	-
3/15/2005	S	1018	3/16/2005	1230	4.7	8.22	8.4	34.6	3/16/2005	1605	-	29.8	-
3/15/2005	C	910	3/16/2005	1230	4.9	8.20	8.2	34.8	3/16/2005	1605	-	30.9	-
3/16/2005	WL	807	3/17/2005	1130	6.7	7.96	7.5	34.0	3/17/2005	1410	-	30.1	-
3/16/2005	ML	1100	3/17/2005	1130	4.4	7.97	7.7	34.4	3/17/2005	1410	-	27.2	-
3/16/2005	EL	1239	3/17/2005	1130	4.7	7.96	7.7	34.1	3/17/2005	1410	-	25.5	-
3/16/2005	NMC	1142	3/17/2005	1130	5.8	7.95	7.2	34.1	3/17/2005	1410	-	26.5	-
3/16/2005	WLC	934	3/17/2005	1130	4.7	7.98	7.8	34.8	3/17/2005	1410	-	28.6	-
10/18/2005	N	1230	10/19/2005	1100	5.7	8.25	10.5	35.1	10/19/2005	1600	1700	27.5	28.5
10/18/2005	S	1318	10/19/2005	1100	6.0	8.29	9.7	34.3	10/19/2005	1600	1700	26.7	27.7
10/18/2005	C	1412	10/19/2005	1100	4.7	8.28	10.4	34.7	10/19/2005	1600	1700	25.8	26.8
10/20/2005	WL	1421	10/21/2005	800	7.7	8.32	7.9	30.9	10/21/2005	1645	1900	26.4	28.7
10/20/2005	ML	1050	10/21/2005	1130	5.8	8.28	7.7	34.4	10/21/2005	1645	1900	29.9	32.2
10/20/2005	EL	927	10/21/2005	1130	5.8	8.25	7.1	33.9	10/21/2005	1645	1900	31.3	33.6
10/20/2005	NMC	1125	10/21/2005	1130	5.8	8.25	7.4	33.2	10/21/2005	1645	1900	29.3	31.6
10/20/2005	WLC	1518	10/21/2005	800	6.2	8.26	7.2	34.3	10/21/2005	1645	1900	25.5	27.7
1/25/2006	N	1003	1/26/2006	1100	3.6	8.20	8.3	32.4	1/26/2006	1505	-	29.0	-
1/25/2006	S	1229	1/26/2006	1100	4.4	8.25	9.6	33.4	1/26/2006	1640	-	28.2	-
1/25/2006	C	1124	1/26/2006	1100	4.8	8.23	8.5	32.9	1/26/2006	1505	-	27.7	-
1/24/2006	WL	1344	1/26/2006	1100	5.4	8.29	9.1	32.9	1/26/2006	1505	-	49.4	-
1/25/2006	ML	807	1/26/2006	1100	2.8	8.26	9.1	26.1	1/26/2006	1640	-	32.6	-
1/25/2006	EL	920	1/26/2006	1100	3.0	8.18	8.2	33.2	1/26/2006	1640	-	31.3	-
1/25/2006	NMC	849	1/26/2006	1100	2.9	8.23	8.7	33.4	1/26/2006	1640	-	31.9	-
1/24/2006	WLC	1305	1/26/2006	1100	5.7	8.51	11.1	30.0	1/26/2006	1505	-	50.0	-

1° Sp. - The primary species for all four sampling events was *Mytilus galloprovincialis* .

2° Sp. - The secondary species was *Strongylocentrotus purpuratus* for the second sampling event and *Crassostrea gigas* for the fourth sampling event.

Dash indicates that no secondary species was involved in sampling event.

Table E-1 (cont.). Sample handling details

Sampling Date	Sample ID	Sampling Time	Received at SSC-SD Date	Time	Temp (°C)	pH (SU)	D.O. (mg/L)	Salinity (ppt)	Test Initiation Date	Time 1° Sp.	Time 2° Sp.	Elapsed Time (hrs) Collection to Testing 1° Sp.	2° Sp.
5/16/2006	N	1106	5/17/2006	1030	3.6	8.55	7.2	34.0	5/17/2006	1700	1545	29.9	28.7
5/16/2006	S	1246	5/17/2006	1030	5.4	8.45	7.9	32.9	5/17/2006	1700	1545	28.2	27.0
5/16/2006	C	1324	5/17/2006	1030	5.4	8.43	8.2	33.4	5/17/2006	1700	1545	27.6	26.4
5/17/2006	WL	852	5/18/2006	1050	4.5	8.21	8.0	33.0	5/18/2006	1515	1430	30.4	29.6
5/17/2006	ML	1015	5/18/2006	1050	5.7	8.25	7.3	33.5	5/18/2006	1515	1430	29.0	28.3
5/16/2006	EL	932	5/17/2006	1030	5.1	8.42	7.9	33.2	5/17/2006	1700	1545	31.5	30.2
5/17/2006	NMC	1100	5/18/2006	1050	6.0	8.26	7.8	34.0	5/18/2006	1515	1430	28.3	27.5
5/17/2006	WLC	930	5/18/2006	1050	4.2	8.23	8.3	32.0	5/18/2006	1515	1430	29.8	29.0

1° Sp. - The primary species for all four sampling events was *Mytilus galloprovincialis* .

2° Sp. - The secondary species was *Strongylocentrotus purpuratus* for the second sampling event and *Crassostrea gigas* for the fourth sampling event.

APPENDIX F

WER: TEST SPECIES SELECTION

TEST SPECIES SELECTION

WER studies typically use two species: the primary species, which is used in a minimum of three sampling events; and a secondary species, which is tested alongside the primary species for one event, for confirmatory reasons (USEPA, 1994). For this study, the Mediterranean mussel (*Mytilus galloprovincialis*) was selected as the primary species, as it is one of two recommended species for WER studies (USEPA, 1994) and has a copper toxicity endpoint (embryo-larval development) that is near the Criterion Maximum Concentration (CMC) (4.8 µg Cu/L). The current national WQC for copper is based solely on toxicity data for this species and endpoint (USEPA, 1995). The secondary species chosen was the Pacific oyster (*Crassostrea gigas*), which is present in Pearl Harbor, is similar in sensitivity to the mussel, yet is taxonomically different, as required by the WER guidance. The oyster could not be used as the primary species because of its limited spawning season, which would be impractical because the tests require large numbers of embryos. Although not required, embryo-larval development tests with the purple sea urchin (*Strongylocentrotus purpuratus*), another EPA-recommended species, were also included for one event, bringing the number of species evaluated to three.

Species selection was based primarily on recommendations contained in the WER Guidance (USEPA, 1994). Note that although the primary test species (*Mytilus galloprovincialis*) does not occur at the site, the WER Guidance specifically states that using indigenous organisms for a WER is not required (USEPA, 1994); Charles Delos, U.S. EPA Office of Water, verified that using these organisms is not a requirement. Several key criteria, however, should be met (USEPA, 1994). Test organisms should

- Be readily available throughout the testing period
- Have a high chance of test success
- Have been tested by other laboratories for comparison purposes in laboratory water
- Be appropriately sensitive (i.e., close to, but above the CMC to which they were to be applied) to the metal

Three resident organisms were considered but deemed inappropriate for use. The Pacific Oyster (*Crassostrea gigas*), which is present in Pearl Harbor and is comparably sensitive to copper, as *M. galloprovincialis*, spawns only during the summer months. Therefore, it was impractical for use as the primary test organism in this study, which spanned multiple seasons. It was suitable, however, as a secondary test species, since the one required event could be coordinated around its spawning season.

The Hawaiian collector urchin (*Tripneustes gratilla*) fertilization test is currently used by National Pollution Discharge Elimination System permittees in Hawaii, but the method was still under review by EPA during the decision-making phase of this study. This species is also very sensitive to handling and does not transport well, may be hard to obtain, can result in failed spawns or unacceptable control success, and can yield variable toxicity results with copper, depending on the sperm:egg ratio required (Nacci, 1992). These factors make it a poor candidate for the WER study. Unlike embryological development, the fertilization test endpoint is not used in derivation of water quality criteria (USEPA, 1985).

The SSC San Diego laboratory also investigated the practicality of including the mangrove oyster (*Isognomon californicum*) in this study. This species was tested in the early 1990s (Ringwood, 1992) and was briefly considered by the EPA for inclusion in the national saltwater copper toxicity database, but has since been eliminated. Only one relevant data point is available for this species in the peer-reviewed literature (Ringwood, 1992). Specimens collected from an open coastal site by the University of Hawaii (John Zardus), did not survive the shipment (less than 24 hours) to San Diego, California. Individuals of this species are very small and may have frozen during the shipment. Therefore, it was concluded that this species did not meet the criteria, as discussed above, for WER studies.

APPENDIX F REFERENCES

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APPENDIX G

WER: WATER QUALITY FROM TOXICITY TESTS

Table G-1. Water quality data from *Mytilus galloprovincialis* toxicity tests from Event 1.

Water Type	Sample ID	Nominal Cu Conc. (µg/L)	pH (SU)			D.O. (mg/l)			Temperature (°C)			Salinity (‰)		
			Min.	Max.	Mean	Min.	Max.	Mean	Min.	Max.	Mean	Min.	Max.	Mean
Lab	SIO 1	0	7.8	7.8	7.8	6.6	7.8	7.3	17.8	18.6	18.2	32.1	33.4	32.7
		2.9	7.8	7.8	7.8	6.8	7.6	7.3	17.7	18.0	17.9	32.6	33.7	33.0
		4.1	7.8	7.9	7.8	6.8	7.9	7.5	18.0	18.6	18.2	32.1	33.9	33.0
		5.9	7.8	7.9	7.8	6.8	7.7	7.3	17.7	18.7	18.1	32.7	33.5	33.1
		8.4	7.8	7.9	7.8	6.6	7.7	7.3	17.9	18.8	18.2	32.2	33.3	32.8
		12	7.8	7.9	7.8	6.6	7.7	7.3	17.7	18.8	18.2	33.2	34.3	33.6
		17.2	7.8	7.9	7.8	7.0	7.6	7.4	18.0	18.7	18.2	33.3	34.1	33.7
Lab	SIO 2	0	7.7	7.9	7.8	7.0	7.2	7.1	17.8	19.4	18.4	32.7	33.1	33.0
		2.9	7.7	7.9	7.8	7.1	7.2	7.1	17.8	18.8	18.2	32.9	33.5	33.1
		4.1	7.8	7.9	7.8	6.9	7.1	7.0	17.8	19.0	18.2	33.1	33.6	33.3
		5.9	7.8	7.9	7.8	6.9	7.1	7.0	17.8	19.1	18.3	33.3	33.5	33.4
		8.4	7.8	7.9	7.8	7.0	7.0	7.0	17.8	18.9	18.2	33.3	33.5	33.4
		12	7.8	7.9	7.8	6.9	7.3	7.1	17.8	19.3	18.4	33.3	33.6	33.4
		17.2	7.8	7.9	7.8	6.8	7.3	7.0	17.8	19.1	18.3	33.4	33.8	33.6
Lab	GC 1	0	7.7	7.9	7.8	6.7	7.7	7.3	17.8	18.7	18.3	32.2	32.5	32.4
		2.9	7.8	7.8	7.8	6.6	7.8	7.3	17.7	18.6	18.1	32.8	33.0	32.9
		4.1	7.7	7.8	7.8	6.6	7.7	7.2	17.7	18.8	18.2	33.0	33.2	33.1
		5.9	7.7	7.8	7.8	6.6	7.7	7.3	17.9	18.7	18.2	32.0	33.0	32.5
		8.4	7.7	7.8	7.8	6.5	7.7	7.3	18.0	18.8	18.3	32.4	33.1	32.7
		12	7.7	7.8	7.8	6.5	7.6	7.2	17.7	18.8	18.2	33.0	33.6	33.2
		17.2	7.7	7.8	7.8	6.5	7.8	7.3	17.9	18.9	18.3	32.7	34.5	33.5
Lab	GC 2	0	7.6	7.8	7.7	6.9	7.8	7.2	18.0	18.6	18.3	33.4	34.0	33.8
		2.9	7.6	7.8	7.7	6.9	8.1	7.3	18.0	18.9	18.6	33.3	34.1	33.7
		4.1	7.6	7.8	7.7	6.9	7.7	7.2	18.1	18.7	18.5	33.0	34.0	33.4
		5.9	7.6	7.8	7.7	6.9	7.8	7.2	18.0	18.8	18.5	33.3	34.1	33.7
		8.4	7.6	7.8	7.7	6.8	7.9	7.2	18.1	19.1	18.6	33.3	34.0	33.7
		12	7.6	7.8	7.7	6.9	7.5	7.1	18.1	19.3	18.7	33.3	34.0	33.7
		17.2	7.6	7.9	7.8	7.0	7.7	7.3	18.1	19.2	18.5	34.0	34.3	34.1
Site	N	0	7.8	8.0	7.9	7.1	8.5	7.8	17.6	18.2	17.8	31.6	33.4	32.2
		2.9	7.8	8.0	7.9	6.9	8.5	7.7	17.2	18.1	17.7	31.6	33.6	32.9
		4.1	7.8	8.0	7.9	6.8	7.8	7.4	17.8	18.2	18.0	32.5	33.7	33.2
		5.9	7.8	8.0	7.9	6.8	8.0	7.5	17.7	18.2	18.0	32.8	34.0	33.4
		8.4	7.8	8.0	7.9	6.8	8.2	7.5	17.8	18.3	18.1	32.2	33.7	33.1
		12	7.8	8.0	7.9	6.7	8.3	7.6	17.7	18.3	18.1	32.8	34.0	33.3
		17.2	7.8	8.0	7.9	6.7	8.1	7.5	17.8	18.3	18.1	32.1	33.7	33.0
Site	S	0	7.7	8.0	7.9	6.8	9.0	7.8	17.8	18.3	18.0	32.3	33.9	33.0
		2.9	7.8	8.0	7.9	7.1	8.3	7.7	17.7	18.1	17.9	32.3	33.6	32.9
		4.1	7.8	8.0	7.9	7.2	8.1	7.6	17.8	18.3	18.1	32.4	33.9	33.0
		5.9	7.8	8.0	7.9	6.9	8.1	7.5	17.7	18.3	18.0	33.0	34.2	33.4
		8.4	7.8	8.0	7.9	7.0	7.9	7.5	17.8	18.3	18.1	32.4	34.1	33.2
		12	7.8	8.0	7.9	7.1	7.9	7.6	17.7	18.3	18.0	32.2	33.6	32.9
		17.2	7.8	8.0	7.9	7.3	8.1	7.7	17.7	18.6	18.1	32.6	34.1	33.2

Table G-1. Water quality data from *Mytilus galloprovincialis* toxicity tests from Event 1. (cont)

Water Type	Sample ID	Nominal Cu Conc. (µg/L)	pH (SU)			D.O. (mg/l)			Temperature (°C)			Salinity (‰)		
			Min.	Max.	Mean	Min.	Max.	Mean	Min.	Max.	Mean	Min.	Max.	Mean
Site	C	0	7.7	8.0	7.8	7.1	8.8	7.8	17.7	18.8	18.2	31.5	33.7	32.6
		2.9	7.8	8.0	7.9	7.3	7.9	7.5	17.6	18.0	17.8	32.9	33.8	33.3
		4.1	7.8	8.0	7.9	7.3	7.5	7.4	17.7	18.0	17.8	32.3	34.0	33.1
		5.9	7.8	8.0	7.9	7.2	7.6	7.4	17.6	18.0	17.8	32.9	34.2	33.4
		8.4	7.8	8.0	7.9	7.2	7.5	7.4	17.7	18.0	17.8	32.6	34.0	33.3
		12	7.8	8.0	7.9	6.6	7.5	7.1	17.3	18.0	17.7	32.6	34.0	33.3
		17.2	7.8	8.0	7.9	7.5	8.1	7.7	17.7	18.2	18.0	32.4	33.5	33.0
Site	WL	0	7.8	7.9	7.9	7.1	8.0	7.4	18.2	18.9	18.6	33.9	34.8	34.2
		2.9	7.8	7.9	7.9	7.1	8.1	7.5	18.2	19.2	18.6	34.0	35.2	34.4
		4.1	7.8	7.9	7.9	7.0	7.9	7.4	18.2	19.3	18.6	33.9	35.0	34.5
		5.9	7.8	7.9	7.9	7.0	7.9	7.3	18.2	19.3	18.7	33.9	35.1	34.6
		8.4	7.8	7.9	7.9	6.9	8.3	7.4	18.3	19.3	18.8	33.9	35.0	34.5
		12	7.8	7.9	7.9	7.0	8.4	7.5	18.2	19.2	18.6	33.9	35.0	34.5
		17.2	7.8	7.9	7.9	6.9	8.3	7.4	18.1	19.3	18.6	33.9	35.0	34.4
Site	ML	0	7.8	7.9	7.9	7.1	8.0	7.4	18.2	18.8	18.5	33.9	34.9	34.3
		2.9	7.8	7.9	7.9	7.1	8.2	7.5	18.2	18.8	18.5	34.2	34.9	34.5
		4.1	7.8	7.9	7.9	7.1	8.3	7.5	18.2	18.9	18.5	34.1	34.9	34.4
		5.9	7.8	7.9	7.9	7.1	8.2	7.5	18.2	18.8	18.6	34.0	35.0	34.4
		8.4	7.8	7.9	7.9	7.1	8.3	7.5	18.2	18.9	18.6	34.3	35.1	34.6
		12	7.9	7.9	7.9	7.0	8.2	7.4	18.2	18.8	18.5	34.4	35.1	34.6
		17.2	7.8	7.9	7.9	7.0	8.1	7.4	18.3	18.9	18.5	34.0	35.2	34.5
Site	EL	0	7.8	7.9	7.9	7.1	8.1	7.4	18.0	18.6	18.4	33.4	35.2	34.1
		2.9	7.8	7.9	7.9	7.0	8.1	7.4	17.9	18.6	18.3	33.9	35.2	34.4
		4.1	7.8	7.9	7.9	7.0	8.0	7.4	17.9	18.6	18.4	34.0	35.2	34.4
		5.9	7.9	7.9	7.9	7.0	8.0	7.4	17.9	18.4	18.2	33.9	35.2	34.4
		8.4	7.8	7.9	7.9	7.1	8.1	7.4	17.9	18.8	18.5	33.9	35.1	34.4
		12	7.9	7.9	7.9	7.0	7.8	7.3	18.0	18.6	18.3	34.2	35.0	34.5
		17.2	7.8	7.9	7.9	7.0	8.0	7.4	18.0	18.8	18.5	33.9	35.1	34.4
Site	NMC	0	7.8	7.9	7.8	6.9	8.0	7.3	17.7	18.8	18.3	34.0	34.7	34.2
		2.9	7.8	7.9	7.9	6.9	7.9	7.3	18.3	18.6	18.4	33.9	34.9	34.3
		4.1	7.8	7.9	7.8	7.0	8.0	7.3	18.2	18.8	18.6	34.5	35.0	34.7
		5.9	7.8	7.9	7.9	7.0	7.9	7.3	18.3	18.6	18.4	34.1	35.0	34.5
		8.4	7.8	7.9	7.9	6.9	7.9	7.3	18.3	18.6	18.5	33.9	35.1	34.5
		12	7.8	7.9	7.9	7.0	8.2	7.4	18.2	18.7	18.4	34.0	35.1	34.4
		17.2	7.8	7.9	7.9	7.1	7.8	7.3	18.4	18.6	18.5	34.0	35.1	34.4
Site	WLC	0	7.8	7.9	7.8	6.9	7.8	7.2	18.2	18.6	18.5	33.8	35.0	34.3
		2.9	7.8	7.9	7.9	6.8	7.6	7.1	18.3	18.4	18.3	34.2	35.0	34.5
		4.1	7.9	7.9	7.9	6.9	7.7	7.2	18.3	18.8	18.6	34.2	35.0	34.6
		5.9	7.9	7.9	7.9	7.0	7.9	7.5	18.2	18.5	18.3	34.2	34.9	34.5
		8.4	7.8	7.9	7.9	7.1	7.9	7.5	18.4	18.8	18.5	34.3	35.1	34.6
		12	7.9	7.9	7.9	7.1	7.8	7.5	18.2	18.8	18.5	34.3	35.2	34.7
		17.2	7.8	7.9	7.9	7.1	7.8	7.5	18.2	18.8	18.5	34.1	35.3	34.5

Table G-2. Water quality data from *Mytilus galloprovincialis* toxicity tests from Event 2.

Water Type	Sample ID	Nominal Cu Conc. (µg/L)	pH (SU) Min.	pH (SU) Max.	pH (SU) Mean	D.O. (mg/l) Min.	D.O. (mg/l) Max.	D.O. (mg/l) Mean	Temperature (°C) Min.	Temperature (°C) Max.	Temperature (°C) Mean	Salinity (‰) Min.	Salinity (‰) Max.	Salinity (‰) Mean
Lab	SIO 1	0	8.0	8.0	8.0	7.1	7.9	7.6	14.8	15.4	15.1	34.1	34.5	34.3
		2.9	7.9	8.0	8.0	7.2	7.7	7.4	14.8	15.6	15.3	33.4	33.8	33.5
		4.1	7.9	8.0	7.9	7.4	7.9	7.6	14.8	15.9	15.2	33.8	33.8	33.8
		5.9	7.9	8.0	8.0	7.2	7.8	7.5	14.7	15.5	15.2	33.6	33.8	33.7
		8.4	7.9	8.0	7.9	7.2	7.9	7.5	14.8	15.3	15.0	33.8	33.9	33.8
		12	7.9	8.0	7.9	7.4	7.9	7.6	14.8	15.9	15.2	33.9	33.9	33.9
		17.2	7.9	8.0	8.0	7.2	7.8	7.5	14.8	15.5	15.2	33.9	34.0	33.9
		24	7.9	8.0	8.0	7.2	7.9	7.5	14.8	15.5	15.0	33.9	33.9	33.9
Lab	SIO 2	0	8.0	8.0	8.0	7.0	7.6	7.4	14.6	14.8	14.7	34.2	34.7	34.4
		2.9	8.0	8.0	8.0	7.2	7.8	7.5	14.1	15.3	14.6	34.2	34.7	34.4
		4.1	7.9	8.0	8.0	7.2	7.6	7.5	14.1	14.5	14.3	34.2	35.4	34.7
		5.9	7.9	8.0	8.0	7.2	7.7	7.5	14.2	15.3	14.7	34.2	34.9	34.6
		8.4	7.9	8.0	8.0	7.2	7.7	7.5	14.1	14.5	14.3	34.3	35.9	35.1
		12	7.9	8.0	8.0	7.4	7.8	7.6	14.2	15.2	14.7	34.3	34.6	34.4
		17.2	7.9	8.0	8.0	7.4	7.8	7.6	14.1	14.6	14.3	34.4	35.4	34.8
		24	7.9	8.0	8.0	7.4	7.9	7.7	13.9	15.3	14.7	34.4	34.9	34.7
Lab	GC 1	0	8.0	8.1	8.1	7.0	7.6	7.3	15.1	15.9	15.5	34.7	35.1	34.9
		2.9	7.8	8.0	7.9	7.1	7.8	7.5	15.0	15.9	15.5	34.2	34.4	34.3
		4.1	7.8	8.0	7.9	6.9	7.8	7.4	14.8	16.0	15.2	34.4	35.1	34.7
		5.9	7.8	7.9	7.9	7.2	7.8	7.5	14.7	15.9	15.3	34.0	34.4	34.3
		8.4	7.8	7.9	7.9	7.5	7.9	7.6	14.5	15.3	14.8	34.5	35.5	34.9
		12	7.8	7.9	7.9	7.6	7.8	7.7	14.6	15.9	15.1	34.4	34.7	34.6
		17.2	7.8	7.9	7.9	7.4	7.9	7.7	14.6	15.5	15.2	34.4	34.6	34.5
		24	7.8	7.9	7.9	7.5	7.9	7.7	14.6	15.4	14.9	34.4	34.6	34.5
Lab	GC 2	0	7.9	7.9	7.9	7.4	7.6	7.5	14.1	14.8	14.5	34.7	34.9	34.8
		2.9	7.8	7.9	7.9	7.4	7.9	7.6	14.0	15.1	14.6	34.7	35.0	34.9
		4.1	7.8	7.9	7.9	7.6	7.7	7.6	13.8	14.6	14.3	34.8	35.6	35.1
		5.9	7.8	7.9	7.8	7.4	7.7	7.6	13.9	15.4	14.7	34.8	35.1	35.0
		8.4	7.8	7.9	7.8	7.4	7.7	7.6	13.9	14.8	14.4	34.8	35.1	35.0
		12	7.8	7.9	7.8	7.3	7.7	7.5	14.0	14.9	14.5	34.7	35.1	34.9
		17.2	7.8	7.9	7.8	7.2	7.7	7.5	14.0	14.5	14.3	34.7	35.5	35.1
		24	7.8	7.9	7.8	7.5	7.8	7.6	14.1	15.3	14.7	34.9	35.0	35.0
Site	N	0	8.0	8.1	8.0	7.3	7.9	7.6	15.2	15.6	15.4	35.1	35.4	35.3
		2.9	8.0	8.1	8.0	7.6	7.8	7.7	15.1	15.7	15.4	35.2	35.4	35.3
		4.1	8.0	8.1	8.0	7.5	7.9	7.6	14.9	16.0	15.3	35.4	35.5	35.4
		5.9	8.0	8.1	8.0	7.4	7.8	7.6	15.0	15.4	15.3	35.1	35.4	35.2
		8.4	8.0	8.1	8.0	7.2	8.1	7.7	14.8	15.4	15.1	35.1	35.4	35.3
		12	8.0	8.1	8.0	7.4	7.8	7.6	15.0	16.0	15.5	35.4	35.4	35.4
		17.2	8.0	8.1	8.0	7.6	8.0	7.8	15.0	15.7	15.2	35.4	35.5	35.5
		24	8.0	8.1	8.0	7.5	7.8	7.7	15.0	15.5	15.3	35.3	35.5	35.4
		35	8.0	8.1	8.0	7.5	7.8	7.7	15.0	15.5	15.3	35.4	35.5	35.4
Site	S	0	8.0	8.2	8.1	7.4	7.8	7.5	15.4	16.0	15.7	34.6	35.3	34.9
		2.9	8.0	8.1	8.0	7.3	7.8	7.6	15.4	15.7	15.6	34.6	34.8	34.7
		4.1	8.0	8.1	8.1	7.4	7.8	7.6	15.0	15.9	15.4	32.6	34.7	34.0
		5.9	8.0	8.1	8.1	7.5	7.8	7.6	15.1	15.6	15.4	34.6	35.0	34.8
		8.4	8.0	8.1	8.1	7.5	7.9	7.7	15.0	15.7	15.2	34.6	35.3	34.9
		12	8.0	8.1	8.1	7.4	7.8	7.6	15.2	16.0	15.5	34.6	34.8	34.7
		17.2	8.0	8.1	8.0	7.3	7.8	7.6	15.2	15.8	15.4	34.7	34.7	34.7
		24	8.0	8.1	8.0	7.3	7.8	7.6	15.1	15.6	15.3	34.6	34.8	34.7
		35	8.0	8.1	8.0	7.4	7.8	7.6	15.2	15.6	15.4	34.6	34.7	34.7

Table G-2 . Water quality data from *Mytilus galloprovincialis* toxicity tests from Event 2. (cont)

Water Type	Sample ID	Nominal Cu Conc. (µg/L)	pH (SU)			D.O. (mg/l)			Temperature (°C)			Salinity (‰)		
			Min.	Max.	Mean	Min.	Max.	Mean	Min.	Max.	Mean	Min.	Max.	Mean
Site	C	0	8.0	8.1	8.1	7.5	7.8	7.6	15.1	15.7	15.4	34.9	35.2	35.0
		2.9	8.0	8.1	8.1	7.4	7.7	7.5	15.1	15.8	15.5	34.8	34.9	34.9
		4.1	8.0	8.1	8.1	7.4	7.9	7.6	15.0	16.0	15.3	34.9	35.0	34.9
		5.9	8.0	8.1	8.1	7.5	7.8	7.6	15.0	15.7	15.4	34.8	34.9	34.8
		8.4	8.0	8.1	8.1	7.5	7.9	7.7	15.0	15.6	15.2	34.4	35.0	34.8
		12	8.0	8.1	8.1	7.5	7.9	7.7	15.0	16.0	15.4	34.9	35.0	35.0
		17.2	8.0	8.1	8.0	7.4	8.0	7.7	15.0	15.7	15.3	35.0	35.0	35.0
		24	8.0	8.1	8.0	7.4	8.0	7.6	15.0	15.7	15.3	34.9	35.0	35.0
		35	8.0	8.1	8.0	7.4	7.8	7.6	15.0	15.9	15.5	34.8	35.0	34.9
Site	WL	0	7.9	8.1	8.0	7.4	7.6	7.5	14.7	15.2	15.0	31.4	31.7	31.6
		2.9	8.0	8.1	8.1	7.1	7.8	7.5	14.5	15.8	15.0	31.0	31.5	31.2
		4.1	8.0	8.1	8.1	7.1	7.9	7.6	14.6	15.3	14.9	31.2	32.4	31.6
		5.9	8.0	8.1	8.1	7.4	7.8	7.6	14.8	16.0	15.6	31.0	32.0	31.4
		8.4	8.0	8.1	8.1	7.4	7.9	7.7	14.6	15.2	14.9	31.0	32.0	31.5
		12	8.0	8.1	8.1	7.3	7.8	7.5	14.6	15.8	15.1	31.4	32.0	31.7
		17.2	8.0	8.1	8.1	7.4	7.9	7.6	14.8	15.1	14.9	31.4	32.2	31.7
		24	8.0	8.1	8.1	7.5	7.7	7.6	15.0	16.0	15.4	31.0	32.7	31.7
		35	8.0	8.1	8.1	7.4	7.8	7.6	15.0	15.3	15.1	31.6	32.9	32.1
Site	ML	0	7.9	8.1	8.0	7.5	7.8	7.7	14.1	15.1	14.6	34.4	35.2	34.8
		2.9	7.9	8.1	8.0	7.4	7.7	7.5	14.0	15.4	14.7	34.6	34.8	34.7
		4.1	8.0	8.1	8.0	7.5	7.8	7.6	14.0	14.9	14.6	34.7	35.8	35.1
		5.9	7.9	8.1	8.0	7.6	7.8	7.7	14.0	15.7	14.9	34.3	35.2	34.8
		8.4	8.0	8.1	8.0	7.7	7.9	7.8	13.9	15.1	14.7	35.0	35.2	35.1
		12	8.0	8.1	8.0	7.5	7.9	7.7	14.0	15.4	14.8	34.8	35.5	35.1
		17.2	8.0	8.1	8.0	7.6	7.7	7.6	14.1	14.8	14.5	34.8	35.5	35.1
		24	8.0	8.1	8.0	7.5	7.7	7.6	14.1	15.7	14.9	34.8	35.0	34.9
		35	8.0	8.1	8.0	7.5	7.8	7.6	14.1	15.1	14.7	34.8	36.5	35.4
Site	EL	0	8.0	8.1	8.0	7.6	7.8	7.7	14.3	15.4	14.9	34.1	34.4	34.3
		2.9	8.0	8.1	8.0	7.5	7.8	7.6	14.1	15.7	14.9	34.0	34.1	34.1
		4.1	8.0	8.1	8.0	7.5	7.8	7.6	14.1	15.1	14.7	34.4	35.2	34.7
		5.9	8.0	8.1	8.0	7.5	7.6	7.5	14.2	15.8	15.1	34.1	34.8	34.5
		8.4	8.0	8.1	8.0	7.4	7.8	7.5	14.3	15.3	14.9	34.4	35.1	34.7
		12	8.0	8.1	8.0	7.5	7.8	7.6	14.2	15.6	15.0	34.3	35.1	34.6
		17.2	8.0	8.1	8.0	7.6	7.7	7.6	14.3	15.1	14.8	34.4	35.1	34.7
		24	8.0	8.1	8.0	7.6	7.8	7.7	14.4	15.8	15.1	34.4	35.2	34.8
		35	8.0	8.1	8.0	7.6	7.8	7.7	14.3	15.2	14.9	34.4	36.0	35.0
Site	NMC	0	8.0	8.1	8.1	7.1	7.5	7.3	14.8	15.1	15.0	33.4	33.9	33.7
		2.9	8.0	8.1	8.0	7.4	7.7	7.6	14.6	14.9	14.8	32.4	33.6	32.9
		4.1	8.0	8.1	8.0	7.6	7.7	7.7	14.7	15.1	14.8	33.6	35.3	34.2
		5.9	8.0	8.1	8.0	7.5	7.8	7.7	14.6	15.2	14.9	33.8	35.4	34.4
		8.4	8.0	8.1	8.0	7.5	7.8	7.6	14.6	14.8	14.7	33.9	35.0	34.3
		12	8.0	8.1	8.0	7.6	7.8	7.7	14.5	14.8	14.6	33.8	35.0	34.3
		17.2	8.0	8.1	8.0	7.5	7.7	7.6	14.4	14.8	14.6	34.3	34.7	34.5
		24	8.0	8.1	8.0	7.5	7.7	7.6	14.7	14.9	14.8	33.9	34.3	34.1
		35	8.0	8.1	8.0	7.5	7.7	7.6	14.4	14.8	14.6	34.0	36.0	34.7
Site	WLC	0	8.0	8.1	8.1	7.3	7.7	7.4	14.7	15.0	14.8	32.6	33.3	33.1
		2.9	8.0	8.1	8.1	7.4	7.7	7.5	14.6	15.1	14.8	32.5	33.2	32.8
		4.1	8.0	8.1	8.0	7.3	7.7	7.4	14.6	14.8	14.7	33.2	34.0	33.6
		5.9	8.0	8.1	8.1	7.3	7.9	7.5	14.7	14.9	14.8	32.9	34.0	33.3
		8.4	8.0	8.1	8.1	7.4	7.9	7.6	14.6	14.8	14.7	33.2	33.9	33.5
		12	8.0	8.1	8.1	7.4	7.9	7.6	14.6	15.1	14.8	33.1	33.4	33.3
		17.2	8.0	8.1	8.1	7.4	7.8	7.6	14.5	14.8	14.7	33.1	34.0	33.5
		24	8.0	8.1	8.0	7.3	7.9	7.5	14.6	15.2	14.9	33.2	34.0	33.5
		35	8.0	8.1	8.0	7.4	7.8	7.5	14.5	14.8	14.7	33.2	34.6	33.7

Table G-3. Water quality data from *Strongylocentrotus purpuratus* toxicity tests from Event 2.

Water Type	Sample ID	Nominal Cu Conc. (µg/L)	pH (SU) Min.	pH (SU) Max.	pH (SU) Mean	D.O. (mg/l) Min.	D.O. (mg/l) Max.	D.O. (mg/l) Mean	Temperature (°C) Min.	Temperature (°C) Max.	Temperature (°C) Mean	Salinity (‰) Min.	Salinity (‰) Max.	Salinity (‰) Mean
Lab	SIO 1	0	7.9	8.0	8.0	7.1	7.9	7.6	14.8	15.4	15.1	33.7	34.7	34.3
		2.9	7.9	8.0	8.0	7.2	7.7	7.5	14.8	15.6	15.2	33.2	33.9	33.5
		4.1	7.9	8.0	7.9	7.4	7.9	7.7	14.8	15.9	15.0	33.6	34.0	33.8
		5.9	7.9	8.0	8.0	7.2	7.8	7.6	14.7	15.5	15.1	33.5	33.8	33.7
		8.4	7.9	8.0	7.9	7.2	7.9	7.6	14.8	15.3	15.0	33.1	34.0	33.7
		12	7.9	8.0	7.9	7.4	7.9	7.6	14.8	15.9	15.1	33.7	34.0	33.9
		17.2	7.9	8.0	8.0	7.2	7.9	7.6	14.8	15.5	15.1	33.9	34.2	34.0
		24	7.9	8.0	8.0	7.0	7.9	7.4	14.8	15.5	15.0	33.9	34.1	34.0
Lab	SIO 2	0	8.0	8.1	8.0	7.0	7.9	7.6	14.6	15.2	14.8	32.8	34.7	33.9
		2.9	8.0	8.0	8.0	7.2	8.2	7.7	14.1	15.7	15.0	33.7	34.7	34.3
		4.1	7.9	8.0	8.0	7.2	7.9	7.6	14.1	14.7	14.4	34.2	35.4	35.0
		5.9	7.9	8.0	8.0	7.2	7.9	7.6	14.2	15.7	15.0	34.2	35.8	34.9
		8.4	7.9	8.0	8.0	7.2	7.9	7.7	14.1	14.9	14.4	34.3	35.9	35.4
		12	7.9	8.0	8.0	7.4	8.2	7.8	14.2	15.4	15.0	34.2	35.6	34.6
		17.2	7.9	8.0	8.0	7.4	8.1	7.8	14.1	14.6	14.4	34.4	35.6	35.1
		24	7.9	8.0	8.0	7.4	8.0	7.8	13.9	15.5	15.0	34.4	35.7	34.9
Lab	GC 1	0	8.0	8.1	8.1	7.0	7.6	7.3	15.0	15.9	15.4	34.7	35.2	35.0
		2.9	7.8	8.0	8.0	7.1	7.8	7.4	15.0	16.0	15.5	34.2	35.0	34.5
		4.1	7.8	8.0	7.9	6.9	7.8	7.4	14.8	16.0	15.1	34.4	35.6	35.0
		5.9	7.8	8.0	7.9	7.2	7.8	7.5	14.7	15.9	15.2	34.0	36.5	34.8
		8.4	7.8	8.0	7.9	7.5	7.9	7.6	14.5	15.3	14.8	34.5	35.8	35.1
		12	7.8	8.0	7.9	7.5	7.8	7.7	14.6	15.9	15.0	34.4	34.9	34.7
		17.2	7.8	8.0	7.9	7.4	7.9	7.7	14.6	15.5	15.0	34.4	34.9	34.6
		24	7.8	8.0	7.9	7.5	7.9	7.7	14.6	15.4	14.9	34.3	34.8	34.5
Lab	GC 2	0	7.9	8.1	8.0	7.4	8.2	7.7	14.1	15.0	14.6	31.2	34.9	33.8
		2.9	7.8	8.0	7.9	7.4	8.2	7.7	14.0	15.7	15.0	34.3	35.0	34.8
		4.1	7.8	8.0	7.9	7.6	8.2	7.7	13.8	14.6	14.4	34.8	35.6	35.2
		5.9	7.8	8.0	7.9	7.4	8.1	7.7	13.9	15.7	15.0	34.8	36.0	35.3
		8.4	7.8	8.0	7.9	7.4	8.2	7.7	13.9	14.9	14.5	34.8	35.3	35.1
		12	7.8	8.0	7.9	7.3	8.3	7.7	14.0	15.4	14.8	34.7	35.4	35.1
		17.2	7.8	8.0	7.9	7.2	8.2	7.7	14.0	14.6	14.4	34.7	35.6	35.3
		24	7.8	8.0	7.9	7.5	8.2	7.8	14.1	15.5	15.0	34.9	35.9	35.2
Site	N	0	7.9	8.1	8.0	7.3	7.9	7.6	15.0	15.7	15.4	34.3	35.4	35.0
		2.9	7.9	8.1	8.0	7.3	7.8	7.6	15.0	15.7	15.3	35.2	35.4	35.2
		4.1	7.9	8.1	8.0	7.5	7.9	7.7	14.9	16.0	15.2	35.4	35.7	35.5
		5.9	7.9	8.1	8.0	7.4	7.8	7.6	15.0	15.4	15.2	35.1	35.4	35.2
		8.4	7.9	8.1	8.0	7.2	8.1	7.7	14.8	15.4	15.1	35.1	35.6	35.3
		12	7.9	8.1	8.0	7.4	7.8	7.6	15.0	16.0	15.4	35.4	35.5	35.4
		17.2	8.0	8.1	8.0	7.5	8.0	7.7	15.0	15.7	15.2	35.4	35.8	35.6
		24	8.0	8.1	8.0	7.5	7.8	7.7	15.0	15.5	15.3	35.3	35.5	35.4
		35	8.0	8.1	8.0	7.5	7.8	7.7	15.0	15.5	15.3	35.4	35.7	35.5
		50	8.0	8.1	8.0	7.5	8.0	7.7	14.8	15.4	15.0	34.6	35.6	35.0
Site	S	0	8.0	8.2	8.0	7.4	7.8	7.6	15.4	16.0	15.8	34.4	35.3	34.9
		2.9	8.0	8.1	8.0	7.3	7.8	7.6	15.4	15.8	15.6	34.6	34.8	34.7
		4.1	8.0	8.1	8.0	7.4	7.8	7.6	15.0	15.9	15.4	32.5	34.7	33.5
		5.9	8.0	8.1	8.0	7.4	7.8	7.6	15.1	15.7	15.5	34.6	35.5	35.0
		8.4	7.9	8.1	8.0	7.2	7.9	7.6	15.0	15.7	15.3	34.6	35.3	35.0
		12	8.0	8.1	8.0	7.0	7.8	7.5	15.2	16.0	15.6	34.6	34.9	34.8
		17.2	8.0	8.1	8.0	7.3	7.9	7.6	15.2	16.0	15.6	34.7	35.0	34.8
		24	7.9	8.1	8.0	7.3	7.8	7.6	15.1	15.8	15.5	34.6	34.8	34.7
		35	8.0	8.1	8.0	7.3	7.8	7.6	15.2	15.8	15.5	34.6	35.3	34.9
		50	7.9	8.1	8.0	7.4	7.8	7.6	15.1	15.7	15.4	34.6	35.2	34.9
Site	C	0	8.0	8.1	8.0	7.5	7.8	7.7	15.0	15.9	15.4	34.2	35.2	34.9
		2.9	8.0	8.1	8.0	7.4	7.7	7.6	15.1	15.8	15.5	34.8	35.0	34.9
		4.1	8.0	8.1	8.0	7.4	7.9	7.6	15.0	16.0	15.3	34.9	35.2	35.0
		5.9	8.0	8.1	8.0	7.4	7.8	7.6	15.0	15.7	15.4	34.8	34.9	34.8
		8.4	7.9	8.1	8.0	7.5	7.9	7.7	15.0	15.6	15.2	34.3	35.4	34.8
		12	7.9	8.1	8.0	7.5	7.9	7.7	15.0	16.0	15.3	34.9	35.1	35.0
		17.2	7.9	8.1	8.0	7.4	8.0	7.7	15.0	15.7	15.3	35.0	35.4	35.1
		24	7.5	8.1	7.9	7.4	8.0	7.6	15.0	15.7	15.3	34.9	35.4	35.1
		35	7.9	8.1	8.0	7.4	7.8	7.6	15.0	15.9	15.4	34.8	35.2	35.0

Table G-3 . Water quality data from *Strongylocentrotus purpuratus* toxicity tests from Event 2. (cont)

Water Type	Sample ID	Nominal Cu Conc. (µg/L)	pH (SU) Min.	pH (SU) Max.	pH (SU) Mean	D.O. (mg/l) Min.	D.O. (mg/l) Max.	D.O. (mg/l) Mean	Temperature (°C) Min.	Temperature (°C) Max.	Temperature (°C) Mean	Salinity (‰) Min.	Salinity (‰) Max.	Salinity (‰) Mean
Site	WL	0	7.9	8.1	8.0	7.4	8.2	7.7	14.7	15.5	15.2	30.5	32.2	31.5
		2.9	8.0	8.1	8.0	7.1	8.4	7.8	14.5	15.9	15.4	29.7	31.5	30.8
		4.1	8.0	8.1	8.0	7.1	8.1	7.7	14.6	15.3	15.0	31.2	32.4	31.9
		5.9	8.0	8.1	8.0	7.4	8.4	7.8	14.8	16.0	15.7	31.0	32.4	31.8
		8.4	8.0	8.1	8.1	7.4	8.3	7.8	14.6	15.2	14.9	31.0	32.4	31.8
		12	8.0	8.1	8.1	7.3	8.3	7.7	14.6	16.0	15.4	31.4	32.2	31.9
		17.2	8.0	8.1	8.0	7.4	8.4	7.8	14.8	15.2	15.0	31.4	32.2	31.9
		24	8.0	8.1	8.0	7.5	8.4	7.8	15.0	16.0	15.6	31.0	32.7	32.1
		35	8.0	8.1	8.0	7.4	8.4	7.8	15.0	15.3	15.1	31.6	32.9	32.2
		50	8.0	8.1	8.0	7.4	8.4	7.8	15.0	16.0	15.6	31.6	32.2	31.9
Site	ML	0	7.9	8.1	8.0	7.5	8.2	7.8	14.1	15.1	14.7	31.7	35.2	33.8
		2.9	7.9	8.1	8.0	7.4	8.3	7.7	14.0	16.0	15.2	33.4	34.8	34.3
		4.1	8.0	8.1	8.0	7.5	8.2	7.8	14.0	14.9	14.7	34.7	35.8	35.3
		5.9	7.9	8.1	8.0	7.6	8.2	7.8	14.0	15.8	15.2	34.3	35.6	35.1
		8.4	8.0	8.1	8.0	7.7	8.0	7.8	13.9	15.1	14.8	35.0	35.5	35.3
		12	8.0	8.1	8.0	7.5	8.3	7.9	14.0	15.7	15.2	34.8	35.5	35.3
		17.2	8.0	8.1	8.0	7.6	8.1	7.8	14.1	15.0	14.7	34.8	35.6	35.3
		24	8.0	8.1	8.0	7.5	8.2	7.7	14.1	15.7	15.2	34.8	35.0	35.0
		35	8.0	8.1	8.0	7.5	8.2	7.8	14.1	15.1	14.8	34.8	36.5	35.8
		50	8.0	8.1	8.0	7.5	8.3	7.8	14.1	16.0	15.4	34.9	35.5	35.3
Site	EL	0	8.0	8.1	8.0	7.6	8.2	7.8	14.3	15.4	15.0	31.5	34.4	33.4
		2.9	8.0	8.1	8.0	7.5	8.3	7.8	14.1	16.0	15.3	32.8	35.2	34.0
		4.1	8.0	8.1	8.0	7.5	8.2	7.8	14.1	15.2	14.9	34.4	35.2	34.8
		5.9	8.0	8.1	8.0	7.5	8.2	7.7	14.2	15.8	15.3	34.1	35.2	34.7
		8.4	8.0	8.1	8.0	7.4	8.3	7.8	14.3	15.3	14.9	34.4	35.2	34.9
		12	8.0	8.1	8.0	7.5	8.3	7.8	14.2	15.9	15.3	34.3	35.2	34.8
		17.2	8.0	8.1	8.0	7.6	8.4	7.8	14.3	15.4	15.0	34.4	35.2	34.9
		24	8.0	8.1	8.0	7.6	8.3	7.8	14.4	15.9	15.4	34.4	35.2	34.9
		35	8.0	8.1	8.0	7.6	8.2	7.8	14.3	15.2	14.9	34.4	36.0	35.4
		50	8.0	8.1	8.0	7.6	8.3	7.8	14.4	16.0	15.5	34.5	36.0	35.3
Site	NMC	0	8.0	8.1	8.0	7.1	8.3	7.5	14.5	15.1	14.8	32.5	33.9	33.2
		2.9	8.0	8.1	8.0	7.4	8.3	7.7	14.6	15.0	14.8	32.4	33.9	33.3
		4.1	8.0	8.1	8.0	7.4	8.3	7.7	14.4	15.1	14.7	33.6	35.6	34.7
		5.9	8.0	8.1	8.0	7.5	8.2	7.7	14.4	15.2	14.8	33.8	35.9	34.9
		8.4	8.0	8.1	8.0	7.5	8.3	7.7	14.2	14.8	14.5	33.9	35.5	34.7
		12	8.0	8.1	8.0	7.6	8.2	7.8	14.5	14.8	14.7	33.8	35.0	34.3
		17.2	8.0	8.1	8.0	7.5	8.5	7.8	14.3	14.8	14.5	34.3	35.0	34.6
		24	8.0	8.1	8.0	7.5	8.2	7.7	14.2	14.9	14.7	33.9	35.4	34.5
		35	8.0	8.1	8.0	7.5	8.3	7.8	14.3	14.8	14.5	34.0	36.1	35.2
		50	8.0	8.1	8.0	7.5	8.4	7.8	14.1	15.0	14.7	34.0	36.0	34.7
Site	WLC	0	8.0	8.1	8.0	7.3	8.1	7.6	14.4	15.0	14.7	32.1	33.3	32.7
		2.9	8.0	8.1	8.0	7.4	8.4	7.7	14.5	15.1	14.7	32.5	33.2	32.8
		4.1	8.0	8.1	8.0	7.3	8.2	7.6	14.5	14.8	14.6	33.2	34.0	33.7
		5.9	8.0	8.1	8.0	7.3	8.4	7.7	14.4	14.9	14.7	32.9	34.3	33.7
		8.4	8.0	8.1	8.0	7.4	8.3	7.8	14.3	14.8	14.5	33.2	34.1	33.7
		12	8.0	8.1	8.0	7.4	8.2	7.8	14.5	15.1	14.7	33.1	34.1	33.5
		17.2	8.0	8.1	8.0	7.4	8.3	7.8	14.5	14.8	14.7	33.1	34.2	33.7
		24	8.0	8.1	8.0	7.3	8.3	7.7	14.6	15.2	14.8	33.2	34.7	34.0
		35	8.0	8.1	8.0	7.4	8.2	7.7	14.4	14.8	14.6	33.2	34.8	34.1
		50	8.0	8.1	8.0	7.5	8.2	7.7	14.4	15.2	14.8	33.2	34.5	33.8

Table G-4. Water quality data from *Mytilus galloprovincialis* toxicity tests from Event 3.

Water Type	Sample ID	Nominal Cu Conc. (µg/L)	pH (SU)			D.O. (mg/l)			Temperature (°C)			Salinity (‰)		
			Min.	Max.	Mean	Min.	Max.	Mean	Min.	Max.	Mean	Min.	Max.	Mean
Lab	SIO	0	7.9	8.0	7.9	7.2	7.3	7.3	17.1	18.1	17.7	32.9	33.4	33.1
		2.9	7.9	8.0	7.9	7.1	7.3	7.2	17.8	18.0	17.9	33.1	33.4	23.3
		4.1	7.9	8.0	7.9	7.0	7.3	7.2	17.5	18.3	17.9	33.1	33.3	33.2
		5.9	7.9	8.0	7.9	7.0	7.3	7.2	17.5	18.0	17.7	33.1	33.4	33.2
		8.4	7.9	8.0	7.9	7.1	7.6	7.4	16.7	18.0	17.4	33.1	34.5	33.6
		12	7.9	8.0	7.9	7.1	7.6	7.4	17.4	17.9	17.6	33.1	33.4	33.3
		17.2	7.9	8.0	7.9	7.2	7.5	7.4	17.5	17.8	17.7	33.0	33.4	33.2
Lab	GC	0	7.8	8.0	7.9	7.4	7.6	7.5	17.7	18.3	18.1	32.6	33.4	33.0
		2.9	7.8	8.0	7.9	7.1	7.6	7.4	17.7	18.3	18.1	33.3	33.6	33.5
		4.1	7.8	8.0	7.9	7.4	7.5	7.5	17.1	18.3	17.7	32.8	33.5	23.6
		5.9	7.8	8.0	7.9	7.1	7.6	7.4	17.7	18.1	17.9	33.4	33.8	33.6
		8.4	7.8	8.0	7.9	7.4	7.6	7.5	17.5	18.1	17.9	33.4	33.6	33.5
		12	7.8	8.0	7.9	7.1	7.6	7.4	17.5	18.7	18.2	33.4	33.8	33.6
		17.2	7.8	8.0	7.9	7.3	7.6	7.5	17.2	18.7	17.9	33.4	33.8	33.6
Lab	SIO26	0	8.0	8.1	8.0	7.4	7.7	7.5	18.0	18.6	18.3	26.1	26.6	26.3
		2.9	8.0	8.1	8.0	7.4	7.6	7.5	18.3	18.6	18.5	26.0	26.6	26.3
		4.1	7.9	8.1	8.0	7.4	7.6	7.5	18.3	18.9	18.7	26.1	26.6	26.4
		5.9	7.9	8.1	8.0	7.4	7.6	7.5	18.3	18.8	18.6	26.4	26.6	26.5
		8.4	7.9	8.1	8.0	7.4	7.7	7.5	18.3	18.8	18.6	26.4	26.6	26.5
		12	8.0	8.1	8.0	7.4	7.6	7.5	18.3	18.6	18.5	26.4	26.7	26.6
		17.2	8.0	8.0	8.0	7.4	7.5	7.4	18.3	18.8	18.5	26.5	26.6	26.6
Site	N	0	8.0	8.1	8.1	7.2	7.6	7.4	17.6	18.0	17.9	31.8	32.9	32.5
		2.9	8.0	8.1	8.0	7.4	7.8	7.5	17.9	18.8	18.4	32.7	32.9	32.8
		4.1	8.0	8.1	8.0	7.4	7.8	7.5	18.0	18.9	18.5	33.0	32.8	22.8
		5.9	8.0	8.1	8.0	7.3	7.8	7.5	18.0	18.6	18.4	32.8	33.0	32.9
		8.4	8.0	8.1	8.0	7.4	7.8	7.5	17.8	18.6	18.2	32.7	33.0	32.8
		12	8.0	8.1	8.0	7.4	7.9	7.6	17.9	18.6	18.3	32.8	33.0	32.9
		17.2	8.0	8.1	8.0	7.5	7.9	7.6	18.0	18.6	18.4	32.8	32.9	32.9
		24	8.0	8.1	8.0	7.4	8.0	7.6	18.2	18.6	18.5	32.8	32.9	32.9
		35	8.0	8.1	8.0	7.4	8.0	7.6	18.0	18.8	18.5	32.8	32.9	32.9
Site	S	0	8.0	8.1	8.0	7.4	8.0	7.7	17.9	18.1	18.0	32.2	33.4	32.6
		2.9	8.0	8.1	8.0	7.4	8.0	7.6	18.0	18.5	18.3	33.3	33.4	33.3
		4.1	8.0	8.1	8.0	7.4	8.1	7.7	18.3	19.0	18.7	33.3	33.3	33.3
		5.9	8.0	8.1	8.0	7.4	8.1	7.7	18.3	18.8	18.6	33.3	33.5	33.4
		8.4	8.0	8.1	8.0	7.4	8.1	7.6	18.2	19.0	18.6	33.4	33.6	33.5
		12	8.0	8.1	8.0	7.4	8.0	7.6	18.2	18.6	18.4	33.4	33.6	33.5
		17.2	8.0	8.1	8.0	7.4	8.0	7.6	18.3	18.8	18.6	33.4	33.6	33.5
		24	8.0	8.1	8.0	7.3	8.0	7.6	18.3	19.0	18.6	33.4	33.6	33.5
		35	8.0	8.1	8.0	7.4	8.0	7.6	18.3	19.0	18.7	33.4	33.5	33.5

Table G-4. Water quality data from *Mytilus galloprovincialis* toxicity tests from Event 3. (cont)

Water Type	Sample ID	Nominal Cu Conc. (µg/L)	pH (SU) Min.	pH (SU) Max.	pH (SU) Mean	D.O. (mg/l) Min.	D.O. (mg/l) Max.	D.O. (mg/l) Mean	Temperature (°C) Min.	Temperature (°C) Max.	Temperature (°C) Mean	Salinity (‰) Min.	Salinity (‰) Max.	Salinity (‰) Mean
Site	C	0	8.0	8.1	8.0	7.3	7.9	7.6	17.7	18.0	17.9	32.6	33.1	32.8
		2.9	8.0	8.1	8.0	7.4	7.8	7.5	17.8	18.6	18.2	32.9	33.1	33.0
		4.1	8.0	8.1	8.0	7.4	7.8	7.6	18.2	18.9	18.6	32.9	33.1	33.0
		5.9	8.0	8.1	8.0	7.4	7.9	7.6	18.3	18.7	18.5	33.0	33.2	33.1
		8.4	8.0	8.1	8.0	7.4	7.8	7.6	18.0	18.6	18.3	33.0	33.2	33.1
		12	8.0	8.1	8.0	7.4	7.8	7.6	18.0	18.9	18.4	33.0	33.1	23.1
		17.2	8.0	8.1	8.0	7.4	7.9	7.6	18.3	18.6	18.4	33.0	33.3	33.1
		24	8.0	8.1	8.0	7.5	7.9	7.6	18.3	18.9	18.6	33.0	33.2	33.1
		35	8.0	8.1	8.0	7.3	7.9	7.5	18.3	18.9	18.7	33.0	33.2	33.1
Site	WL	0	8.0	8.1	8.0	7.3	8.0	7.6	17.7	19.0	18.2	31.6	32.7	32.0
		2.9	8.0	8.1	8.0	7.1	7.6	7.3	17.1	18.8	18.1	32.7	33.1	32.9
		4.1	8.0	8.1	8.0	7.2	7.6	7.4	17.1	18.8	17.8	31.0	32.9	22.9
		5.9	8.0	8.2	8.1	7.3	7.9	7.6	17.7	19.0	18.2	32.8	33.0	32.9
		8.4	8.0	8.1	8.0	7.3	7.6	7.4	17.7	18.4	18.1	32.7	32.9	32.8
		12	8.0	8.1	8.0	7.2	8.0	7.6	17.7	18.5	18.1	32.7	33.0	32.8
		17.2	8.0	8.1	8.0	7.2	7.6	7.4	17.5	19.0	18.2	32.7	32.9	32.8
		24	8.0	8.1	8.0	7.3	8.0	7.6	17.4	18.4	17.8	32.7	33.0	32.9
		35	8.0	8.1	8.0	7.3	7.6	7.4	17.7	18.3	18.0	32.7	33.0	32.9
Site	ML	0	7.9	8.1	8.0	7.2	7.7	7.4	17.1	18.4	17.9	25.8	26.6	26.3
		2.9	7.9	8.1	8.0	7.3	7.6	7.5	17.4	18.1	17.7	26.3	26.6	26.4
		4.1	7.9	8.1	8.0	7.3	7.6	7.4	17.5	18.3	18.0	26.3	26.5	26.4
		5.9	7.9	8.1	8.0	7.3	7.6	7.5	17.5	18.2	17.9	26.3	26.6	26.4
		8.4	7.9	8.1	8.0	7.5	7.6	7.5	17.5	18.9	18.2	26.3	26.5	26.4
		12	7.9	8.1	8.0	7.3	7.8	7.6	17.6	18.1	17.8	26.4	26.6	26.5
		17.2	8.0	8.1	8.0	7.3	7.6	7.5	17.7	18.2	18.0	26.4	26.6	26.5
		24	8.0	8.1	8.0	7.4	7.8	7.6	17.7	18.9	18.2	26.4	26.6	26.5
		35	7.9	8.1	8.0	7.4	7.6	7.5	17.7	18.9	18.3	26.3	26.8	26.5
Site	EL	0	8.0	8.1	8.0	7.4	7.8	7.6	18.0	18.4	18.1	32.4	33.1	32.9
		2.9	8.0	8.1	8.0	7.4	7.9	7.6	18.3	18.6	18.5	33.1	33.3	33.2
		4.1	8.0	8.1	8.0	7.3	7.9	7.5	18.3	19.0	18.7	33.1	33.3	33.2
		5.9	8.0	8.1	8.0	7.2	7.9	7.5	18.3	18.8	18.5	33.1	33.3	33.2
		8.4	8.0	8.1	8.0	7.4	8.0	7.6	18.3	18.9	18.6	33.1	33.3	33.2
		12	8.0	8.1	8.0	7.3	8.0	7.6	18.2	18.6	18.4	33.2	33.3	33.3
		17.2	8.0	8.1	8.0	7.4	8.0	7.6	18.3	18.8	18.6	33.2	33.4	33.3
		24	8.0	8.1	8.0	7.3	8.0	7.6	18.3	19.0	18.6	33.1	33.4	33.3
		35	8.0	8.1	8.0	7.4	8.0	7.6	18.3	19.0	18.7	33.1	33.3	33.2
Site	NMC	0	8.0	8.1	8.0	7.1	7.6	7.4	17.4	19.0	18.1	32.1	32.9	32.4
		2.9	8.0	8.1	8.0	7.3	7.6	7.4	17.7	18.8	18.1	32.8	33.1	32.9
		4.1	8.0	8.1	8.0	7.4	7.6	7.5	17.7	18.1	17.9	32.8	33.0	32.9
		5.9	8.0	8.1	8.0	7.3	7.6	7.4	17.7	18.8	18.2	32.8	33.1	32.9
		8.4	8.0	8.1	8.0	7.4	7.6	7.5	17.7	18.8	18.3	32.8	33.1	32.9
		12	8.0	8.1	8.0	7.4	7.6	7.5	17.4	18.8	18.1	32.8	33.1	132.3
		17.2	8.0	8.1	8.0	7.4	7.6	7.5	17.2	18.9	18.0	32.7	33.4	33.0
		24	8.0	8.1	8.0	7.5	7.6	7.5	17.7	18.7	18.1	32.8	33.1	33.0
		35	8.0	8.1	8.0	7.4	7.6	7.5	17.6	18.6	18.2	32.8	33.1	33.0
Site	WLC	0	8.0	8.3	8.1	7.3	8.1	7.7	17.7	18.7	18.2	31.2	31.8	31.6
		2.9	8.0	8.3	8.1	7.3	7.6	7.5	17.7	18.7	18.2	31.7	31.8	31.8
		4.1	8.0	8.3	8.1	7.3	7.6	7.5	17.5	19.0	18.2	31.7	31.9	31.8
		5.9	8.0	8.3	8.1	7.3	8.2	7.7	17.0	18.4	17.7	31.7	31.9	31.8
		8.4	8.0	8.3	8.1	7.3	7.7	7.5	17.7	18.3	17.9	31.8	32.2	32.0
		12	8.0	8.3	8.1	7.5	7.6	7.6	17.7	18.8	18.2	31.7	31.9	31.8
		17.2	8.0	8.3	8.1	7.2	8.2	7.7	17.5	18.8	18.0	31.7	31.9	31.8
		24	8.0	8.3	8.1	7.3	7.6	7.5	17.6	18.8	18.1	31.7	31.7	31.7
		35	8.0	8.3	8.1	7.3	8.2	7.7	17.2	18.8	17.8	31.7	31.9	31.8

Table G-5. Water quality data from *Mytilus galloprovincialis* toxicity tests from Event 4.

Water Type	Sample ID	Nominal Cu Conc. (µg/L)	pH (SU)			D.O. (mg/l)			Temperature (°C)			Salinity (‰)		
			Min.	Max.	Mean	Min.	Max.	Mean	Min.	Max.	Mean	Min.	Max.	Mean
Lab	SIO 1	0	8.3	8.3	8.3	6.5	7.4	7.0	17.7	18.3	18.1	32.4	32.6	32.5
		2.9	8.1	8.2	8.1	6.8	7.6	7.1	17.5	18.3	17.9	32.0	33.6	33.0
		4.1	8.0	8.2	8.1	7.0	7.6	7.3	17.7	18.4	17.9	31.0	33.7	32.8
		5.9	8.0	8.2	8.0	6.8	7.0	6.9	17.7	18.5	18.2	31.1	33.7	32.8
		8.4	7.9	8.2	8.0	6.7	6.9	6.8	17.4	18.6	18.0	33.4	33.8	33.6
		12	7.9	8.2	8.0	6.9	7.1	7.0	17.4	18.9	18.2	33.4	33.8	33.6
		17.2	7.9	8.2	8.0	6.4	7.1	6.9	17.4	18.7	18.2	33.4	33.7	33.6
Lab	SIO 2	0	8.0	8.3	8.1	6.8	7.2	7.0	17.6	18.2	17.9	33.8	34.0	33.9
		2.9	8.0	8.0	8.0	6.7	7.3	6.9	17.3	18.3	17.8	33.5	33.8	33.7
		4.1	8.0	8.0	8.0	6.8	7.3	7.0	17.3	18.3	17.8	33.6	33.8	33.7
		5.9	8.0	8.0	8.0	6.8	7.4	7.2	17.2	18.0	17.7	33.6	33.8	33.7
		8.4	8.0	8.0	8.0	6.9	7.6	7.3	17.2	18.0	17.7	33.6	33.6	33.6
		12	7.9	8.0	8.0	7.0	7.6	7.3	17.2	18.1	17.8	33.6	33.7	33.6
		17.2	7.9	8.0	8.0	6.9	7.4	7.2	17.4	18.3	18.0	33.6	33.7	33.7
Lab	GC 1	0	7.8	8.0	7.9	6.3	7.3	6.8	17.5	19.0	18.3	32.2	33.0	32.6
		2.9	7.9	7.9	7.9	6.7	7.4	6.9	17.7	18.8	18.3	32.9	33.9	33.6
		4.1	7.9	7.9	7.9	6.8	7.4	7.1	17.9	18.6	18.4	33.6	34.1	33.9
		5.9	7.9	7.9	7.9	6.8	7.6	7.1	18.0	18.6	18.4	33.7	34.0	33.9
		8.4	7.9	7.9	7.9	6.7	7.3	7.0	17.7	18.7	18.2	33.7	34.0	33.9
		12	7.9	7.9	7.9	6.3	7.6	7.0	17.7	18.8	18.3	33.7	34.0	33.9
		17.2	7.9	7.9	7.9	6.8	7.5	7.1	17.9	18.8	18.4	33.7	34.1	33.9
Lab	GC 2	0	7.7	7.9	7.8	6.9	7.3	7.1	17.5	18.3	18.0	33.5	33.8	33.7
		2.9	7.7	7.9	7.8	6.7	7.8	7.3	17.5	18.4	18.0	33.8	33.9	33.9
		4.1	7.7	7.9	7.8	7.0	7.8	7.4	17.6	18.6	18.1	33.9	34.0	34.0
		5.9	7.7	7.9	7.8	6.8	7.7	7.3	17.6	18.6	18.1	33.9	34.0	34.0
		8.4	7.7	7.9	7.8	7.0	7.7	7.3	17.5	18.6	18.1	33.9	34.0	33.9
		12	7.7	7.9	7.8	6.9	7.8	7.4	17.5	18.4	18.0	34.0	34.0	34.0
		17.2	7.7	7.9	7.8	6.7	7.4	7.1	17.7	18.7	18.1	33.9	34.0	33.9
Site	N	0	8.0	8.2	8.0	6.7	7.1	6.9	17.7	19.0	18.4	33.4	33.9	33.6
		2.9	7.9	8.2	8.0	6.8	7.3	7.1	17.8	18.8	18.3	33.9	34.2	34.1
		4.1	7.9	8.2	8.0	6.7	7.4	7.0	18.0	18.6	18.4	33.9	34.3	34.1
		5.9	7.8	8.2	8.0	6.8	7.4	7.0	18.0	18.6	18.3	33.9	34.3	34.2
		8.4	7.9	8.2	8.0	6.8	7.3	7.0	17.7	18.7	18.2	33.9	34.3	34.1
		12	7.9	8.2	8.0	7.0	7.5	7.2	17.7	18.8	18.3	33.9	34.6	34.3
		17.2	7.9	8.2	8.0	6.8	7.4	7.0	17.9	18.6	18.3	33.9	34.4	34.2
		24	7.9	8.2	8.0	6.6	7.2	6.9	17.9	18.5	18.3	33.9	34.4	34.2
		35	8.0	8.2	8.0	6.8	7.3	7.1	17.7	18.6	18.2	33.9	34.6	34.2
Site	S	0	8.0	8.2	8.1	6.5	6.9	6.8	17.8	18.8	18.3	32.0	33.0	32.3
		2.9	8.0	8.2	8.0	6.8	7.1	6.9	18.0	18.8	18.5	33.1	33.3	33.2
		4.1	7.9	8.2	8.0	6.4	7.2	6.8	18.3	18.9	18.6	33.1	33.3	33.2
		5.9	7.9	8.2	8.1	6.7	7.3	6.9	18.3	18.8	18.6	33.0	33.5	33.3
		8.4	8.0	8.2	8.1	6.4	7.2	6.8	17.8	18.8	18.4	33.1	33.5	33.4
		12	7.9	8.2	8.0	6.9	7.4	7.1	17.9	18.8	18.4	33.2	33.7	33.5
		17.2	8.0	8.2	8.1	6.9	7.4	7.2	18.3	18.9	18.7	33.0	33.4	33.2
		24	8.0	8.2	8.1	6.7	7.5	7.0	18.6	18.8	18.7	32.9	33.3	33.2
		35	7.9	8.2	8.1	6.8	7.0	6.9	18.3	18.9	18.7	32.9	33.2	33.1

Table G-5 . Water quality data from *Mytilus galloprovincialis* toxicity tests from Event 4. (cont)

Water Type	Sample ID	Nominal Cu Conc. (µg/L)	pH (SU) Min.	pH (SU) Max.	pH (SU) Mean	D.O. (mg/l) Min.	D.O. (mg/l) Max.	D.O. (mg/l) Mean	Temperature (°C) Min.	Temperature (°C) Max.	Temperature (°C) Mean	Salinity (‰) Min.	Salinity (‰) Max.	Salinity (‰) Mean
Site	C	0	8.2	8.5	8.3	6.6	7.1	6.9	17.8	18.8	18.4	33.4	33.9	33.7
		2.9	8.0	8.3	8.1	6.7	7.0	6.9	18.0	18.8	18.3	33.5	34.1	33.8
		4.1	8.0	8.2	8.1	6.5	7.1	6.8	18.0	18.8	18.3	33.6	34.1	33.9
		5.9	7.9	8.2	8.1	6.5	7.0	6.8	17.8	18.8	18.2	33.6	34.3	34.0
		8.4	7.9	8.2	8.1	6.9	7.0	7.0	17.4	18.8	18.1	33.6	33.9	33.7
		12	7.9	8.2	8.0	7.0	7.3	7.1	17.7	18.6	18.2	33.6	34.1	33.9
		17.2	7.9	8.2	8.0	7.0	7.0	7.0	18.0	18.8	18.4	33.6	34.0	33.8
		24	7.9	8.2	8.1	7.0	7.1	7.0	18.3	18.8	18.5	33.5	34.0	33.8
		35	7.9	8.2	8.1	7.0	7.2	7.1	17.8	18.8	18.3	33.6	34.0	33.8
Site	WL	0	8.0	8.1	8.0	6.5	7.2	6.7	17.3	19.0	18.2	32.1	32.8	32.5
		2.9	8.0	8.0	8.0	6.7	7.1	6.9	17.4	18.9	18.2	32.0	33.1	32.6
		4.1	8.0	8.0	8.0	6.5	7.2	6.9	17.6	18.8	18.4	32.6	33.0	32.8
		5.9	8.0	8.0	8.0	6.6	7.5	7.1	17.7	18.9	18.5	32.6	33.1	32.9
		8.4	8.0	8.0	8.0	6.6	7.2	7.0	17.7	18.8	18.3	32.7	33.1	32.9
		12	7.9	8.0	8.0	6.8	7.2	7.0	17.5	18.8	18.2	32.7	32.9	32.8
		17.2	8.0	8.0	8.0	6.9	7.3	7.1	17.7	18.8	18.4	32.7	32.9	32.8
		24	8.0	8.0	8.0	6.2	7.2	6.6	17.8	19.0	18.5	32.7	33.1	32.9
		35	8.0	8.0	8.0	6.6	7.2	7.0	17.8	19.0	18.5	32.7	33.0	32.9
Site	ML	0	8.0	8.0	8.0	6.5	7.4	7.0	17.6	18.6	18.0	33.8	34.2	33.9
		2.9	8.0	8.0	8.0	6.7	7.3	7.1	17.5	18.9	18.0	34.0	34.1	34.0
		4.1	8.0	8.0	8.0	6.8	7.6	7.2	17.6	19.0	18.1	33.9	34.0	34.0
		5.9	8.0	8.0	8.0	7.3	7.7	7.4	17.7	19.0	18.2	33.9	34.1	34.0
		8.4	8.0	8.0	8.0	7.1	7.7	7.3	17.7	18.8	18.1	33.9	34.1	34.0
		12	8.0	8.0	8.0	6.9	7.7	7.3	17.7	18.8	18.1	33.9	34.1	34.0
		17.2	8.0	8.0	8.0	6.9	7.3	7.1	17.6	19.0	18.1	33.7	33.8	33.7
		24	8.0	8.0	8.0	6.8	7.3	7.1	17.6	19.0	18.1	33.6	33.8	33.7
		35	8.0	8.0	8.0	6.6	7.3	7.0	17.7	18.9	18.1	33.7	33.8	33.7
Site	EL	0	8.0	8.2	8.1	6.3	7.3	6.8	18.0	18.8	18.4	32.7	32.9	32.8
		2.9	8.0	8.2	8.1	6.4	7.3	6.9	18.0	18.6	18.3	33.6	33.9	33.8
		4.1	8.0	8.2	8.1	6.6	7.0	6.9	17.9	18.5	18.3	33.6	34.0	33.8
		5.9	7.9	8.2	8.0	6.4	7.1	6.9	17.8	18.7	18.3	33.6	34.0	33.8
		8.4	7.9	8.2	8.0	6.3	7.2	6.8	17.2	18.9	18.0	33.6	34.0	33.8
		12	7.9	8.2	8.0	6.0	7.4	6.8	17.7	18.6	18.1	33.7	34.1	33.9
		17.2	7.9	8.2	8.0	6.6	7.3	6.9	17.9	18.6	18.2	33.6	34.1	33.9
		24	7.9	8.2	8.0	6.5	7.1	6.8	17.9	18.9	18.4	33.7	34.0	33.9
		35	7.9	8.2	8.0	6.3	7.4	6.9	17.4	18.8	18.1	33.7	34.1	33.9
Site	NMC	0	8.0	8.1	8.1	6.8	7.1	6.9	17.4	18.4	17.9	34.0	34.1	34.0
		2.9	8.0	8.0	8.0	6.5	7.1	6.8	17.3	18.1	17.8	33.9	34.3	34.1
		4.1	8.0	8.0	8.0	6.7	7.1	6.9	17.3	18.6	18.0	34.0	34.4	34.2
		5.9	8.0	8.0	8.0	6.7	7.3	6.9	17.4	18.3	18.0	34.0	34.3	34.1
		8.4	8.0	8.0	8.0	6.6	7.1	6.8	17.4	18.3	17.9	34.0	34.3	34.1
		12	8.0	8.0	8.0	6.6	7.2	6.8	17.2	18.3	17.7	34.0	34.5	34.2
		17.2	8.0	8.0	8.0	6.5	7.2	6.8	17.4	18.3	18.0	33.9	34.3	34.1
		24	8.0	8.0	8.0	6.6	7.3	6.8	17.5	18.6	18.2	34.0	34.4	34.1
		35	8.0	8.0	8.0	6.1	7.3	6.7	17.5	18.6	18.1	34.0	34.3	34.1
Site	WLC	0	8.0	8.0	8.0	6.7	7.2	7.0	17.8	19.0	18.4	32.1	32.3	32.2
		2.9	8.0	8.0	8.0	6.8	7.2	7.0	17.7	19.0	18.3	32.1	32.3	32.2
		4.1	8.0	8.0	8.0	6.6	7.2	7.0	17.8	19.0	18.5	32.2	32.4	32.3
		5.9	8.0	8.0	8.0	6.6	7.4	7.1	17.8	19.0	18.6	32.1	32.4	32.3
		8.4	8.0	8.0	8.0	7.0	7.2	7.1	17.9	19.0	18.6	32.1	32.4	32.2
		12	8.0	8.0	8.0	6.7	7.2	7.0	17.8	19.0	18.4	32.1	32.4	32.2
		17.2	8.0	8.0	8.0	6.6	7.2	6.8	17.8	19.0	18.4	32.1	32.6	32.3
		24	8.0	8.0	8.0	6.8	7.2	7.0	17.9	19.0	18.6	32.3	32.6	32.5
		35	8.0	8.0	8.0	6.8	7.1	6.9	17.9	19.0	18.6	32.3	32.6	32.5

Table G-6. Water quality data from *Crassostrea gigas* toxicity tests from Event 4.

Water Type	Sample ID	Nominal Cu Conc. (µg/L)	pH (SU)			D.O. (mg/l)			Temperature (°C)			Salinity (‰)		
			Min.	Max.	Mean	Min.	Max.	Mean	Min.	Max.	Mean	Min.	Max.	Mean
Lab	SIO 1	0	8.0	8.2	8.1	6.5	7.2	6.9	19.4	20.8	20.3	33.1	33.3	33.2
Lab	SIO 2	0	8.0	8.1	8.0	6.0	6.5	6.3	20.8	21.0	20.9	33.6	34.1	33.8
		2.9	8.0	8.0	8.0	6.3	6.5	6.4	20.8	21.0	20.9	33.6	34.0	33.8
		4.1	7.9	8.0	8.0	6.3	6.5	6.4	20.8	21.0	20.9	33.5	33.7	33.6
		5.9	7.9	8.0	8.0	6.0	6.6	6.3	20.8	20.9	20.8	33.6	33.7	33.6
		8.4	7.9	8.0	8.0	6.5	7.0	6.7	20.8	20.8	20.8	33.5	33.9	33.7
		12	7.9	8.0	8.0	6.4	6.8	6.6	20.8	21.0	20.9	33.5	33.9	33.7
		17.2	7.9	8.0	8.0	6.5	6.6	6.5	20.8	21.0	20.9	33.6	33.8	33.7
Lab	GC 1	0	7.9	7.9	7.9	6.3	8.4	7.0	19.4	20.8	20.3	33.5	33.9	33.7
Lab	GC 2	0	7.7	8.0	7.8	6.4	6.5	6.5	20.7	21.0	20.8	33.4	33.8	33.6
		2.9	7.7	7.9	7.8	6.4	6.9	6.6	20.8	21.0	20.9	33.9	34.0	34.0
		4.1	7.7	7.9	7.8	6.1	7.2	6.6	20.8	20.9	20.8	34.0	34.1	34.0
		5.9	7.7	7.9	7.8	6.3	6.9	6.6	20.8	21.0	20.9	33.9	34.1	34.0
		8.4	7.7	7.9	7.8	6.4	7.1	6.7	20.7	20.9	20.8	33.8	34.1	33.9
		12	7.7	7.9	7.8	6.4	6.8	6.5	20.8	21.0	20.9	33.9	34.0	33.9
		17.2	7.7	7.9	7.8	6.4	6.5	6.4	20.8	21.0	20.9	33.9	34.1	34.0
Site	N	0	7.9	8.1	8.0	6.1	7.3	6.6	19.0	20.8	20.2	33.9	34.4	34.2
Site	S	0	8.0	8.2	8.1	6.3	7.6	6.8	19.1	20.8	20.2	33.0	33.5	33.3
Site	C	0	7.9	8.2	8.0	6.3	7.5	6.7	19.1	20.8	20.2	33.7	34.0	33.8
Site	WL	0	8.0	8.0	8.0	6.0	6.6	6.2	20.8	21.0	20.9	32.6	32.8	32.7
		2.9	8.0	8.0	8.0	6.2	6.8	6.5	20.8	21.0	20.9	32.7	32.9	32.8
		4.1	8.0	8.0	8.0	6.3	7.2	6.6	20.8	21.0	20.9	32.7	32.8	32.7
		5.9	8.0	8.0	8.0	6.3	7.2	6.6	20.8	21.0	20.9	32.6	33.0	32.8
		8.4	8.0	8.0	8.0	6.2	7.1	6.5	20.8	21.0	20.9	32.7	32.8	32.8
		12	8.0	8.0	8.0	6.4	7.3	6.7	20.8	21.0	20.9	32.7	32.9	32.8
		17.2	8.0	8.0	8.0	6.4	6.8	6.5	20.8	21.0	20.9	32.4	32.9	32.7
		24	8.0	8.0	8.0	6.3	6.4	6.4	20.8	21.0	20.9	32.7	32.9	32.8
		35	8.0	8.0	8.0	6.3	6.5	6.4	20.9	21.0	20.9	32.8	32.9	32.8
Site	ML	0	8.0	8.0	8.0	6.3	6.4	6.4	21.0	21.0	21.0	32.1	33.8	33.2
		2.9	8.0	8.0	8.0	6.3	6.3	6.3	20.8	21.0	20.9	33.9	34.2	34.1
		4.1	7.9	8.0	8.0	6.3	6.9	6.5	20.8	21.0	20.9	34.0	34.2	34.1
		5.9	7.9	8.0	8.0	6.4	6.8	6.6	20.7	21.0	20.9	33.9	34.2	34.1
		8.4	7.9	8.0	8.0	6.3	6.8	6.5	20.7	21.0	20.9	34.0	34.2	34.1
		12	7.9	8.0	8.0	6.4	6.8	6.6	20.8	21.0	20.9	33.9	34.2	34.0
		17.2	7.9	8.0	8.0	6.2	6.5	6.3	20.8	21.0	20.9	33.6	34.2	33.8
		24	7.9	8.0	8.0	6.2	7.0	6.5	20.8	21.0	20.9	33.7	34.0	33.8
		35	7.9	8.0	8.0	6.2	6.9	6.5	20.7	21.0	20.8	33.7	34.0	33.8
Site	EL	0	8.0	8.2	8.1	6.2	7.0	6.5	19.3	20.8	20.3	33.6	34.0	33.8
Site	NMC	0	8.0	8.1	8.0	6.1	6.3	6.2	20.5	21.0	20.8	33.9	34.5	34.3
		2.9	8.0	8.0	8.0	6.2	6.5	6.4	20.7	21.0	20.9	34.0	34.4	34.1
		4.1	8.0	8.0	8.0	6.3	6.5	6.4	20.7	21.0	20.9	34.0	34.4	34.1
		5.9	8.0	8.0	8.0	6.2	6.4	6.3	20.7	21.0	20.9	34.0	34.3	34.2
		8.4	8.0	8.0	8.0	6.1	6.8	6.4	20.8	21.0	20.9	34.0	34.3	34.1
		12	8.0	8.0	8.0	6.3	7.3	6.7	20.8	21.0	20.9	34.0	34.2	34.1
		17.2	8.0	8.0	8.0	6.2	6.6	6.4	20.8	21.0	20.9	34.0	34.3	34.1
		24	8.0	8.0	8.0	6.1	6.2	6.2	20.8	21.0	20.9	33.9	34.1	34.0
		35	8.0	8.0	8.0	6.2	6.7	6.4	20.8	21.0	20.9	34.0	34.3	34.1
Site	WLC	0	8.0	8.0	8.0	6.4	6.6	6.5	20.9	21.0	20.9	31.9	32.4	32.2
		2.9	8.0	8.0	8.0	6.3	7.1	6.6	20.8	21.0	20.9	32.0	32.4	32.2
		4.1	8.0	8.0	8.0	6.4	7.1	6.6	20.7	21.0	20.9	32.1	32.4	32.2
		5.9	8.0	8.0	8.0	6.4	7.2	6.7	20.9	21.0	20.9	32.1	32.3	32.2
		8.4	8.0	8.0	8.0	6.3	7.4	6.7	20.9	21.0	20.9	32.0	32.4	32.2
		12	7.9	8.0	8.0	6.4	7.3	6.7	20.8	21.0	20.9	32.2	32.5	32.3
		17.2	8.0	8.0	8.0	6.2	7.2	6.6	20.9	21.0	20.9	32.2	32.5	32.3
		24	7.9	8.0	8.0	6.4	7.2	6.7	20.9	21.0	20.9	32.3	32.4	32.4
		35	8.0	8.0	8.0	6.0	7.2	6.6	20.8	20.9	20.9	32.1	32.6	32.3

APPENDIX H

WER: CONFIRMATORY COPPER MEASUREMENTS

Table H-1. Confirmatory copper measurements for select concentrations at test initiation and test termination from Event 1 for *Mytilus galloprovincialis*.

	Total Recoverable (µg/L)				Dissolved (µg/L)			
Sample ID	Nominal	Initial	Final	% diff	Nominal	Initial	Final	% diff
SIO 1	12.0	15.8	12.7	80.4	12.0	11.8	9.2	78.0
SIO 2	12.0	15.4	16.0	104.2	12.0	11.3	10.4	92.2
GC 1	12.0	13.3	-	-	12.0	8.7	-	-
GC 2	12.0	13.0	13.6	105.0	12.0	8.8	5.9	67.3
N	12.0	13.9	12.7	91.5	12.0	9.6	7.3	76.0
S	12.0	13.3	8.2	61.5	12.0	10.0	7.3	73.1
C	12.0	13.4	14.4	106.9	12.0	11.0	8.9	81.2
WL	12.0	13.9	11.1	80.0	12.0	7.5	7.2	96.6
ML	12.0	15.1	7.4	49.2	12.0	7.4	7.8	105.0
EL	12.0	14.3	7.3	51.2	12.0	7.4	7.8	104.6
NMC	12.0	14.2	13.5	95.2	12.0	8.3	6.2	74.9
WLC	12.0	12.6	13.3	105.4	12.0	8.8	6.2	70.6

Dash indicates that sample was lost.

Table H-2. Confirmatory copper measurements for select concentrations at test initiation and test termination from Event 2 for *Mytilus galloprovincialis*.

	Total Recoverable (µg/L)				Dissolved (µg/L)			
Sample ID	Nominal	Initial	Final	% diff	Nominal	Initial	Final	% diff
SIO 1	12.0	19.2	13.0	67.7	12.0	13.2	9.6	72.7
SIO 2	12.0	14.5	14.9	102.8	12.0	11.5	11.5	100.0
GC 1	12.0	12.0	12.1	100.8	12.0	10.8	9.0	83.3
GC 2	12.0	12.4	-	-	12.0	10.4	-	-
N	12.0	12.3	12.2	99.2	12.0	10.8	7.0	64.8
S	12.0	13.2	11.2	84.8	12.0	7.4	6.8	91.9
C	12.0	13.6	11.9	87.5	12.0	11.3	7.0	61.9
WL	12.0	13.3	12.8	96.2	12.0	8.2	6.7	81.7
ML	12.0	14.3	11.9	83.2	12.0	10.6	7.6	71.7
EL	12.0	14.4	12.5	86.8	12.0	8.8	8.0	90.9
NMC	12.0	13.8	-	-	12.0	10.6	-	-
WLC	12.0	13.3	12.5	94.0	12.0	9.6	7.1	74.0

Dash indicates that sample was lost.

Table H-3. Confirmatory copper measurements for select concentrations at test initiation and test termination from Event 2 for *Strongylocentrotus purpuratus*.

	Total Recoverable (µg/L)				Dissolved (µg/L)			
Sample ID	Nominal	Initial	Final	% diff	Nominal	Initial	Final	% diff
SIO 1	17.0	21.5	-	-	17.0	14.8	15.3	103.4
SIO 2	17.0	21.7	21.1	97.2	17.0	17.4	15.1	86.8
GC 1	17.0	20.0	18.4	92.0	17.0	16.5	13.6	82.4
GC 2	17.0	19.0	-	-	17.0	15.7	-	-
N	17.0	23.1	19.1	82.7	17.0	14.9	13.1	87.9
S	17.0	20.7	17.4	84.1	17.0	12.9	11.6	89.9
C	17.0	20.4	17.1	83.8	17.0	13.6	12.2	89.7
WL	17.0	21.2	18.8	88.7	17.0	12.3	10.1	82.1
ML	17.0	21.0	17.5	83.3	17.0	13.2	11.6	87.9
EL	17.0	20.6	18.3	88.8	17.0	14.5	11.9	82.1
NMC	17.0	21.4	20.6	96.3	17.0	14.6	12.2	83.6
WLC	17.0	20.0	18.0	90.0	17.0	12.8	10.0	78.1

Dash indicates that sample was lost.

Table H-4. Confirmatory copper measurements for select concentrations at test initiation and test termination from Event 3 for *Mytilus galloprovincialis*.

	Total Recoverable (µg/L)				Dissolved (µg/L)			
Sample ID	Nominal	Initial	Final	% diff	Nominal	Initial	Final	% diff
SIO	12.0	16.7	11.3	67.9	12.0	11.9	6.3	52.8
SIO26	12.0	16.0	13.5	84.7	12.0	10.1	11.1	110.6
GC	12.0	13.2	7.6	57.4	12.0	10.0	5.3	52.8
N	12.0	17.2	-	-	12.0	12.0	-	-
S	12.0	17.0	11.2	66.3	12.0	11.6	11.1	96.0
C	12.0	16.9	6.8	40.1	12.0	9.5	5.3	55.7
WL	12.0	14.7	8.3	56.5	12.0	9.5	12.0	126.1
ML	12.0	16.3	15.6	95.9	12.0	11.6	9.5	81.5
EL	12.0	17.4	11.5	65.9	12.0	11.2	10.5	93.3
NMC	12.0	12.5	-	-	12.0	10.6	-	-
WLC	12.0	15.7	10.8	68.7	12.0	9.1	11.2	123.7

Dash indicates that sample was lost.

Table H-5. Confirmatory copper measurements for select concentrations at test initiation and test termination from Event #4 for *Mytilus galloprovincialis* and *Crassostrea gigas*.

Sample ID	Total Recoverable (µg/L)			
	Nominal	Initial	Final	% diff
SIO 1	12.0	21.3	24.8	116.5
SIO 2	12.0	17.9	16.4	91.6
GC 1	12.0	16.7	19.2	114.8
GC 2	12.0	14.9	13.1	87.8
N	12.0	17.1	19.7	115.5
S	12.0	19.6	14.0	71.6
C	12.0	17.1	16.3	95.5
WL	12.0	16.1	11.8	73.1
ML	12.0	15.8	12.7	80.3
EL	12.0	19.4	15.3	79.1
NMC	12.0	15.7	13.3	84.6
WLC	12.0	17.2	13.3	77.1

APPENDIX I

TOXICITY TEST CONTROL DATA

Table I-1. Control data for *Mytilus galloprovincialis* for all events.

Event #	Initiation Date	Water Type	Sample ID	% Normal		% Normal Survival			
				Mean	S.D.	Mean	S.D.	*p*	% of SIO
1	3/15/2005	Lab	SIO 1	98	1.2	90	7.3	n/a	100
1	3/15/2005	Lab	GC 1	98	0.5	90	13.7	n/a	100
1	3/15/2005	Site	N	98	0.7	89	8.1	0.39	98
1	3/15/2005	Site	S	98	1.0	83	4.8	0.05	92
1	3/15/2005	Site	C	97	1.4	91	11.1	0.42	101
1	3/16/2005	Lab	SIO 2	97	1.7	91	4.7	n/a	100
1	3/16/2005	Lab	GC 2	97	2.1	91	9.2	n/a	100
1	3/16/2005	Site	WL	97	0.8	92	14.7	0.43	101
1	3/16/2005	Site	ML	96	2.2	89	4.9	0.27	98
1	3/16/2005	Site	EL	97	1.8	88	2.5	0.15	97
1	3/16/2005	Site	NMC	97	0.6	88	5.2	0.19	97
1	3/16/2005	Site	WLC	95	1.4	85	6.7	0.09	94
2	10/19/2005	Lab	SIO 1	84	4.2	75	5.2	n/a	100
2	10/19/2005	Lab	GC 1	79	4.1	80	9.3	n/a	106
2	10/19/2005	Site	N	84	3.7	75	8.9	0.50	100
2	10/19/2005	Site	S	83	3.0	76	6.3	0.32	102
2	10/19/2005	Site	C	83	5.7	76	4.0	0.35	102
2	10/21/2005	Lab	SIO 2	87	2.0	83	11.3	n/a	100
2	10/21/2005	Lab	GC 2	82	5.3	84	8.3	n/a	101
2	10/21/2005	Site	WL	88	3.8	74	2.7	0.07	89
2	10/21/2005	Site	ML	81	7.3	85	5.0	0.38	102
2	10/21/2005	Site	EL	88	2.1	80	5.3	0.29	96
2	10/21/2005	Site	NMC	85	5.3	88	12.9	0.28	106
2	10/21/2005	Site	WLC	86	3.6	84	4.7	0.44	101
3	1/26/2006	Lab	SIO	91	5.8	87	9.9	n/a	100
3	1/26/2006	Lab	SIO26	86	4.5	81	6.5	n/a	93
3	1/26/2006	Lab	GC	91	0.5	84	7.3	n/a	96
3	1/26/2006	Site	N	92	2.2	81	7.1	0.13	92
3	1/26/2006	Site	S	89	2.7	87	10.5	0.46	99
3	1/26/2006	Site	C	89	3.9	79	4.0	0.07	90
3	1/26/2006	Site	WL	94	1.9	87	7.0	0.47	99
3	1/26/2006	Site	ML	90	3.2	79	8.7	0.10	98
3	1/26/2006	Site	EL	92	2.3	99	24.3	0.18	114
3	1/26/2006	Site	NMC	88	3.5	78	9.1	0.08	89
3	1/26/2006	Site	WLC	93	3.1	87	4.0	0.47	100
4	5/17/2006	Lab	SIO1	82	3.9	77	3.3	n/a	100
4	5/17/2006	Lab	GC1	82	6.2	74	8.0	n/a	95
4	5/17/2006	Site	N	89	4.0	82	2.8	0.02	106
4	5/17/2006	Site	S	88	3.0	76	6.2	0.32	98
4	5/17/2006	Site	C	82	1.1	79	6.7	0.33	102
4	5/17/2006	Site	EL	89	1.8	76	5.0	0.30	98
4	5/18/2006	Lab	SIO2	96	1.4	92	6.6	n/a	100
4	5/18/2006	Lab	GC2	98	0.9	89	4.3	n/a	96
4	5/18/2006	Site	WL	98	1.4	94	12.6	0.39	102
4	5/18/2006	Site	ML	95	1.1	92	8.7	0.48	100
4	5/18/2006	Site	NMC	97	0.8	95	10.2	0.34	103
4	5/18/2006	Site	WLC	97	0.8	96	7.3	0.21	104

Table I-2. Control data for *Strongylocentrotus purpuratus* for Event 2.

Event #	Initiation Date	Water Type	Sample ID	% Normal		% Normal Survival			
				Mean	S.D.	Mean	S.D.	*p*	% of SIO
2	10/19/2005	Lab	SIO 1	92	2.3	78	9.9	n/a	100
2	10/19/2005	Lab	GC 1	93	1.0	83	9.9	n/a	107
2	10/19/2005	Site	N	93	2.6	86	4.9	0.067	111
2	10/19/2005	Site	S	90	1.7	87	11.3	0.097	112
2	10/19/2005	Site	C	95	2.3	87	1.8	0.053	112
2	10/21/2005	Ref	SIO 2	91	1.6	75	7.2	n/a	100
2	10/21/2005	Lab	GC 2	90	2.1	85	6.2	n/a	113
2	10/21/2005	Site	WL	71	4.3	67	7.6	0.064	89
2	10/21/2005	Site	ML	83	3.4	81	17.7	0.240	109
2	10/21/2005	Site	EL	82	5.4	75	8.7	0.478	100
2	10/21/2005	Site	NMC	95	0.8	93	7.2	0.002	124
2	10/21/2005	Site	WLC	93	2.3	89	6.8	0.006	119

Table I-3. Control data for *Crassostrea gigas* for Event #4.

Event #	Initiation Date	Water Type	Sample ID	% Normal		% Normal Survival			
				Mean	S.D.	Mean	S.D.	*p*	% of SIO
4	5/17/2006	Lab	SIO 1	90	3.6	56	6.5	n/a	100
4	5/17/2006	Lab	GC 1	91	1.7	57	7.2	n/a	102
4	5/17/2006	Site	N	86	3.8	58	7.8	0.343	103
4	5/17/2006	Site	S	97	2.8	86	13.6	0.002	154
4	5/17/2006	Site	C	92	7.8	80	10.2	0.001	144
4	5/17/2006	Site	EL	95	4.1	86	12.0	0.001	154
4	5/18/2006	Lab	SIO 2	92	1.9	87	6.6	n/a	100
4	5/18/2006	Lab	GC 2	94	1.3	86	4.9	n/a	99
4	5/18/2006	Site	WL	94	3.4	84	11.7	0.348	97
4	5/18/2006	Site	ML	93	0.9	84	4.4	0.238	97
4	5/18/2006	Site	NMC	95	2.9	81	10.8	0.156	93
4	5/18/2006	Site	WLC	97	1.8	87	6.3	0.450	101

APPENDIX J

TOXICITY TEST RESULTS (ALL DATA)

Table J-1. Initial density vials for primary species (*Mytilus galloprovincialis*).

Replicate	Event #1 (3/16/2005)	Event #1 (3/17/2005)	Event #2 (10/19/2005)	Event #2 (10/21/2005)	Event #3 (1/26/2006)	Event #4 (5/17/2006)	Event #4 (5/18/2006)
A	189	173	149	118	170	147	198
B	174	173	126	139	175	140	205
C	197	167	130	129	163	155	176
D	174	135	141	130	190	160	183
E	161	158	133	134	145	-	206
Mean	**179**	**161**	**136**	**130**	**169**	**151**	**194**
S.D.	**14.1**	**15.9**	**9.2**	**7.8**	**16.5**	**8.8**	**13.5**

Table J-2. Initial density vials for secondary species (*Strongylocentrotus purpuratus* for Event #2 and *Crassostrea gigas* Event 4).

Replicate	Event #2 (10/19/2005)	Event #2 (10/21/2005)	Event #4 (5/17/2006)	Event #4 (5/18/2006)
A	162	214	150	177
B	179	205	153	203
C	184	199	140	198
D	155	218	147	182
E	161	209	145	175
Mean	**168**	**209**	**147**	**187**
S.D.	**12.6**	**7.4**	**4.9**	**12.7**

Sampling Event #1: 3/15/2005
Test Initiation Date: 3/16/2005
Species: *Mytilus galloprovincialis*
Sample ID: SIO 1

Nominal [Cu] (µg/l)	Rep	Final # Normal	# Abnormal	Percent Normal (%)	Normal Survival (%)
0	a	170	5	97	95
0	b	153	3	98	85
0	c	150	0	100	84
0	d	154	4	97	86
0	e	180	1	99	101
4.1	a	163	8	95	91
4.1	b	146	3	98	82
4.1	c	158	6	96	88
4.1	d	166	5	97	93
4.1	e	188	5	97	105
5.9	a	114	47	71	64
5.9	b	159	18	90	89
5.9	c	152	41	79	85
5.9	d	136	30	82	76
5.9	e	86	78	52	48
8.4	a	170	12	93	95
8.4	b	129	46	74	72
8.4	c	136	14	91	76
8.4	d	113	33	77	63
8.4	e	130	18	88	73
12.0	a	0	168	0	0
12.0	b	0	197	0	0
12.0	c	0	170	0	0
12.0	d	0	165	0	0
12.0	e	0	155	0	0
17.2	a	0	150	0	0
17.2	b	0	150	0	0
17.2	c	0	150	0	0
17.2	d	0	150	0	0
17.2	e	0	150	0	0

Sampling Event #1: 3/15/2005
Test Initiation Date: 3/16/2005
Species: *Mytilus galloprovincialis*
Sample ID: GC 1

Nominal [Cu] (µg/l)	Rep	Final # Normal	# Abnormal	Percent Normal (%)	Normal Survival (%)
0	a	151	4	97	84
0	b	174	2	99	97
0	c	148	3	98	83
0	d	197	4	98	110
0	e	135	3	98	75
4.1	a	184	4	98	103
4.1	b	157	3	98	88
4.1	c	146	3	98	82
4.1	d	171	5	97	96
4.1	e	170	4	98	95
5.9	a	153	3	98	85
5.9	b	156	2	99	87
5.9	c	168	8	95	94
5.9	d	127	6	95	71
5.9	e	159	4	98	89
8.4	a	143	31	82	80
8.4	b	80	80	50	45
8.4	c	146	12	92	82
8.4	d	141	25	85	79
8.4	e	104	10	91	58
12.0	a	28	123	19	16
12.0	b	9	152	6	5
12.0	c	0	150	0	0
12.0	d	2	169	1	1
12.0	e	1	164	1	1
17.2	a	0	150	0	0
17.2	b	0	150	0	0
17.2	c	0	150	0	0
17.2	d	0	150	0	0
17.2	e	0	150	0	0

Sampling Event #1: 3/16/2005
Test Initiation Date: 3/17/2005
Species: ***Mytilus galloprovincialis***
Sample ID: SIO 2

Nominal [Cu] (µg/l)	Rep	Final # Normal	# Abnormal	Percent Normal (%)	Normal Survival (%)
0	a	156	1	99	97
0	b	147	8	95	91
0	c	135	5	96	84
0	d	147	6	96	91
0	e	144	5	97	89
4.1	a	144	2	99	89
4.1	b	145	6	96	90
4.1	c	139	8	95	86
4.1	d	149	7	96	93
4.1	e	111	2	98	69
5.9	a	151	7	96	94
5.9	b	130	12	92	81
5.9	c	123	28	81	76
5.9	d	143	8	95	89
5.9	e	149	8	95	93
8.4	a	113	29	80	70
8.4	b	152	9	94	94
8.4	c	126	37	77	78
8.4	d	139	24	85	86
8.4	e	137	24	85	85
12.0	a	0	160	0	0
12.0	b	1	147	1	1
12.0	c	0	135	0	0
12.0	d	0	158	0	0
12.0	e	0	137	0	0
17.2	a	0	118	0	0
17.2	b	0	147	0	0
17.2	c	0	129	0	0
17.2	d	0	132	0	0
17.2	e	0	128	0	0

Sampling Event #1: 3/16/2005
Test Initiation Date: 3/17/2005
Species: ***Mytilus galloprovincialis***
Sample ID: GC 2

Nominal [Cu] (µg/l)	Rep	Final # Normal	# Abnormal	Percent Normal (%)	Normal Survival (%)
0	a	137	4	97	85
0	b	124	8	94	77
0	c	155	3	98	96
0	d	158	7	96	98
0	e	155	1	99	96
4.1	a	141	10	93	88
4.1	b	140	2	99	87
4.1	c	142	4	97	88
4.1	d	167	3	98	104
4.1	e	126	10	93	78
5.9	a	148	2	99	92
5.9	b	144	8	95	89
5.9	c	136	5	96	84
5.9	d	141	6	96	88
5.9	e	123	7	95	76
8.4	a	134	7	95	83
8.4	b	140	7	95	87
8.4	c	144	6	96	89
8.4	d	146	11	93	91
8.4	e	142	6	96	88
12.0	a	13	150	8	8
12.0	b	19	144	12	12
12.0	c	14	129	10	9
12.0	d	15	121	11	9
12.0	e	1	129	1	1
17.2	a	0	156	0	0
17.2	b	0	145	0	0
17.2	c	0	138	0	0
17.2	d	0	150	0	0
17.2	e	0	147	0	0

Sampling Event #1: 3/15/2005
Test Initiation Date: 3/16/2005
Species: *Mytilus galloprovincialis*
Sample ID: N

Nominal [Cu] (µg/l)	Rep	Final # Normal	# Abnormal	Percent Normal (%)	Normal Survival (%)
0	a	170	2	99	95
0	b	156	2	99	87
0	c	135	4	97	75
0	d	169	3	98	94
0	e	164	4	98	92
4.1	a	150	3	98	84
4.1	b	156	3	98	87
4.1	c	137	7	95	77
4.1	d	141	3	98	79
4.1	e	157	6	96	88
5.9	a	162	0	100	91
5.9	b	144	6	96	80
5.9	c	141	0	100	79
5.9	d	149	4	97	83
5.9	e	159	5	97	89
8.4	a	154	5	97	86
8.4	b	163	3	98	91
8.4	c	170	6	97	95
8.4	d	146	4	97	82
8.4	e	165	2	99	92
12.0	a	157	26	86	88
12.0	b	81	86	49	45
12.0	c	101	60	63	56
12.0	d	111	76	59	62
12.0	e	130	31	81	73
17.2	a	0	170	0	0
17.2	b	0	171	0	0
17.2	c	1	160	1	1
17.2	d	2	157	1	1
17.2	e	0	163	0	0

Sampling Event #1: 3/15/2005
Test Initiation Date: 3/16/2005
Species: *Mytilus galloprovincialis*
Sample ID: S

Nominal [Cu] (µg/l)	Rep	Final # Normal	# Abnormal	Percent Normal (%)	Normal Survival (%)
0	a	150	2	99	84
0	b	148	4	97	83
0	c	142	3	98	79
0	d	139	3	98	78
0	e	161	0	100	90
2.9	a	154	4	97	86
2.9	b	157	2	99	88
2.9	c	150	0	100	84
2.9	d	166	1	99	93
2.9	e	182	2	99	102
4.1	a	174	2	99	97
4.1	b	185	3	98	103
4.1	c	153	3	98	85
4.1	d	153	7	96	85
4.1	e	164	4	98	92
5.9	a	151	0	100	84
5.9	b	161	4	98	90
5.9	c	170	3	98	95
5.9	d	141	5	97	79
5.9	e	183	0	100	102
8.4	a	161	3	98	90
8.4	b	167	5	97	93
8.4	c	168	8	95	94
8.4	d	148	6	96	83
8.4	e	155	2	99	87
12.0	a	130	36	78	73
12.0	b	92	65	59	51
12.0	c	24	115	17	13
12.0	d	66	100	40	37
12.0	e	51	116	31	28
17.2	a	0	153	0	0
17.2	b	0	150	0	0
17.2	c	0	160	0	0
17.2	d	0	158	0	0
17.2	e	0	150	0	0

Sampling Event #1: 3/15/2005
Test Initiation Date: 3/16/2005
Species: *Mytilus galloprovincialis*
Sample ID: C

Nominal [Cu] (µg/l)	Rep	Final # Normal	# Abnormal	Percent Normal (%)	Normal Survival (%)
0	a	147	8	95	82
0	b	139	5	97	78
0	c	186	3	98	104
0	d	177	5	97	99
0	e	169	4	98	94
4.1	a	157	2	99	88
4.1	b	173	3	98	97
4.1	c	151	4	97	84
4.1	d	167	2	99	93
4.1	e	193	1	99	108
5.9	a	156	4	98	87
5.9	b	136	7	95	76
5.9	c	141	6	96	79
5.9	d	172	2	99	96
5.9	e	148	2	99	83
8.4	a	145	15	91	81
8.4	b	158	8	95	88
8.4	c	161	9	95	90
8.4	d	157	5	97	88
8.4	e	163	2	99	91
12.0	a	4	161	2	2
12.0	b	24	118	17	13
12.0	c	55	128	30	31
12.0	d	35	157	18	20
12.0	e	38	119	24	21
17.2	a	0	170	0	0
17.2	b	1	177	1	1
17.2	c	0	169	0	0
17.2	d	0	151	0	0
17.2	e	0	180	0	0

Sampling Event #1: 3/16/2005
Test Initiation Date: 3/17/2005
Species: *Mytilus galloprovincialis*
Sample ID: WL

Nominal [Cu] (µg/l)	Rep	Final # Normal	# Abnormal	Percent Normal (%)	Normal Survival (%)
0	a	186	6	97	116
0	b	127	4	97	79
0	c	133	5	96	83
0	d	154	4	97	96
0	e	139	2	99	86
4.1	a	157	5	97	98
4.1	b	157	1	99	98
4.1	c	142	4	97	88
4.1	d	109	3	97	68
4.1	e	123	3	98	76
5.9	a	125	3	98	78
5.9	b	119	4	97	74
5.9	c	146	10	94	91
5.9	d	127	17	88	79
5.9	e	123	3	98	76
8.4	a	151	0	100	94
8.4	b	132	4	97	82
8.4	c	142	5	97	88
8.4	d	114	6	95	71
8.4	e	139	2	99	86
12.0	a	123	15	89	76
12.0	b	131	4	97	81
12.0	c	130	5	96	81
12.0	d	137	4	97	85
12.0	e	157	6	96	98
17.2	a	100	34	75	62
17.2	b	42	93	31	26
17.2	c	66	86	43	41
17.2	d	54	86	39	34
17.2	e	98	58	63	61
24.0	a	0	140	0	0
24.0	b	0	151	0	0
24.0	c	0	135	0	0
24.0	d	0	141	0	0
24.0	e	0	151	0	0

Sampling Event #1: 3/16/2005
Test Initiation Date: 3/17/2005
Species: *Mytilus galloprovincialis*
Sample ID: ML

Nominal [Cu] (µg/l)	Rep	Final # Normal	# Abnormal	Percent Normal (%)	Normal Survival (%)
0	a	136	10	93	84
0	b	153	7	96	95
0	c	136	5	96	84
0	d	149	3	98	93
0	e	139	2	99	86
4.1	a	149	7	96	93
4.1	b	133	9	94	83
4.1	c	136	4	97	84
4.1	d	147	0	100	91
4.1	e	151	1	99	94
5.9	a	151	3	98	94
5.9	b	142	1	99	88
5.9	c	118	1	99	73
5.9	d	136	3	98	84
5.9	e	149	2	99	93
8.4	a	127	4	97	79
8.4	b	157	1	99	98
8.4	c	143	0	100	89
8.4	d	139	5	97	86
8.4	e	140	1	99	87
12.0	a	131	2	98	81
12.0	b	134	7	95	83
12.0	c	134	13	91	83
12.0	d	142	8	95	88
12.0	e	141	4	97	88
17.2	a	76	62	55	47
17.2	b	8	106	7	5
17.2	c	17	111	13	11
17.2	d	18	123	13	11
17.2	e	30	110	21	19
24.0	a	0	87	0	0
24.0	b	0	134	0	0
24.0	c	0	65	0	0
24.0	d	0	78	0	0
24.0	e	0	62	0	0

Sampling Event #1: 3/16/2005
Test Initiation Date: 3/17/2005
Species: *Mytilus galloprovincialis*
Sample ID: EL

Nominal [Cu] (µg/l)	Rep	Final # Normal	# Abnormal	Percent Normal (%)	Normal Survival (%)
0	a	144	7	95	89
0	b	147	8	95	91
0	c	140	3	98	87
0	d	138	2	99	86
0	e	138	2	99	86
4.1	a	143	2	99	89
4.1	b	121	5	96	75
4.1	c	151	2	99	94
4.1	d	136	5	96	84
4.1	e	140	0	100	87
5.9	a	142	3	98	88
5.9	b	122	6	95	76
5.9	c	138	2	99	86
5.9	d	130	5	96	81
5.9	e	144	6	96	89
8.4	a	117	6	95	73
8.4	b	147	2	99	91
8.4	c	150	10	94	93
8.4	d	141	4	97	88
8.4	e	136	4	97	84
12.0	a	140	4	97	87
12.0	b	142	1	99	88
12.0	c	136	2	99	84
12.0	d	157	5	97	98
12.0	e	157	4	98	98
17.2	a	53	95	36	33
17.2	b	37	102	27	23
17.2	c	25	126	17	16
17.2	d	11	124	8	7
17.2	e	60	74	45	37
24.0	a	0	120	0	0
24.0	b	0	120	0	0
24.0	c	0	120	0	0
24.0	d	0	120	0	0
24.0	e	0	120	0	0

Sampling Event #1: 3/16/2005
Test Initiation Date: 3/17/2005
Species: *Mytilus galloprovincialis*
Sample ID: NMC

Nominal [Cu] (µg/l)	Rep	Final # Normal	# Abnormal	Percent Normal (%)	Normal Survival (%)
0	a	140	4	97	87
0	b	129	5	96	80
0	c	147	5	97	91
0	d	139	3	98	86
0	e	151	5	97	94
4.1	a	145	6	96	90
4.1	b	166	5	97	103
4.1	c	151	2	99	94
4.1	d	176	4	98	109
4.1	e	154	5	97	96
5.9	a	138	3	98	86
5.9	b	150	4	97	93
5.9	c	163	7	96	101
5.9	d	167	6	97	104
5.9	e	157	4	98	98
8.4	a	140	6	96	87
8.4	b	137	4	97	85
8.4	c	145	7	95	90
8.4	d	121	15	89	75
8.4	e	155	3	98	96
12.0	a	102	49	68	63
12.0	b	115	40	74	71
12.0	c	87	50	64	54
12.0	d	135	29	82	84
12.0	e	130	25	84	81
17.2	a	16	160	9	10
17.2	b	11	140	7	7
17.2	c	43	106	29	27
17.2	d	12	136	8	7
17.2	e	8	147	5	5
24.0	a	0	161	0	0
24.0	b	0	161	0	0
24.0	c	0	161	0	0
24.0	d	0	161	0	0
24.0	e	0	161	0	0

Sampling Event #1: 3/16/2005
Test Initiation Date: 3/17/2005
Species: *Mytilus galloprovincialis*
Sample ID: WLC

Nominal [Cu] (µg/l)	Rep	Final # Normal	# Abnormal	Percent Normal (%)	Normal Survival (%)
0	a	151	5	97	94
0	b	129	7	95	80
0	c	125	6	95	78
0	d	145	9	94	90
0	e	136	10	93	84
4.1	a	151	2	99	94
4.1	b	129	4	97	80
4.1	c	138	3	98	86
4.1	d	127	3	98	79
4.1	e	147	12	92	91
5.9	a	152	2	99	94
5.9	b	157	3	98	98
5.9	c	109	1	99	68
5.9	d	131	3	98	81
5.9	e	132	2	99	82
8.4	a	148	7	95	92
8.4	b	138	8	95	86
8.4	c	143	12	92	89
8.4	d	143	11	93	89
8.4	e	148	8	95	92
12.0	a	114	26	81	71
12.0	b	121	25	83	75
12.0	c	129	15	90	80
12.0	d	128	12	91	80
12.0	e	126	33	79	78
17.2	a	0	146	0	0
17.2	b	2	146	1	1
17.2	c	1	133	1	1
17.2	d	2	134	1	1
17.2	e	5	137	4	3
24.0	a	0	120	0	0
24.0	b	0	120	0	0
24.0	c	0	134	0	0
24.0	d	0	105	0	0
24.0	e	0	140	0	0

Sampling Event #2: 10/18/2005
Test Initiation Date: 10/19/2005
Species: *Mytilus galloprovincialis*
Sample ID: SIO 1

Nominal [Cu] (µg/l)	Rep	Final # Normal	# Abnormal	Percent Normal (%)	Normal Survival (%)
0	a	110	14	89	81
0	b	95	19	83	70
0	c	94	24	80	69
0	d	102	14	88	75
0	e	107	26	80	79
2.9	a	80	52	61	59
2.9	b	51	74	41	38
2.9	c	49	73	40	36
2.9	d	68	49	58	50
2.9	e	69	48	59	51
4.1	a	56	70	44	41
4.1	b	46	61	43	34
4.1	c	67	70	49	49
4.1	d	72	52	58	53
4.1	e	65	54	55	48
5.9	a	5	117	4	4
5.9	b	9	129	7	7
5.9	c	10	125	7	7
5.9	d	2	140	1	1
5.9	e	13	120	10	10
8.4	a	0	-	0	0
8.4	b	0	-	0	0
8.4	c	0	-	0	0
8.4	d	0	-	0	0
8.4	e	0	-	0	0
12.0	a	0	-	0	0
12.0	b	0	-	0	0
12.0	c	0	-	0	0
12.0	d	0	-	0	0
12.0	e	0	-	0	0

Dash indicates that vial was thoroughly scanned for the presence of normal embryos.

Sampling Event #2: 10/18/2005
Test Initiation Date: 10/19/2005
Species: *Mytilus galloprovincialis*
Sample ID: GC 1

Nominal [Cu] (µg/l)	Rep	Final # Normal	# Abnormal	Percent Normal (%)	Normal Survival (%)
0	a	115	23	83	85
0	b	120	29	81	88
0	c	117	32	79	86
0	d	96	22	81	71
0	e	93	35	73	68
2.9	a	115	28	80	85
2.9	b	111	24	82	82
2.9	c	94	27	78	69
2.9	d	100	20	83	74
2.9	e	98	25	80	72
4.1	a	80	37	68	59
4.1	b	87	37	70	64
4.1	c	89	25	78	65
4.1	d	85	29	75	63
4.1	e	90	30	75	66
5.9	a	41	71	37	30
5.9	b	55	79	41	40
5.9	c	63	66	49	46
5.9	d	37	73	34	27
5.9	e	52	81	39	38
8.4	a	1	116	1	1
8.4	b	0	-	0	0
8.4	c	0	-	0	0
8.4	d	0	-	0	0
8.4	e	0	-	0	0
12.0	a	0	-	0	0
12.0	b	0	-	0	0
12.0	c	0	-	0	0
12.0	d	0	-	0	0
12.0	e	0	-	0	0

Sampling Event #2: 10/20/2005
Test Initiation Date: 10/21/2005
Species: *Mytilus galloprovincialis*
Sample ID: SIO 2

Nominal [Cu] (µg/l)	Rep	Final # Normal	# Abnormal	Percent Normal (%)	Normal Survival (%)
0	a	88	14	86	68
0	b	107	17	86	82
0	c	101	15	87	78
0	d	119	22	84	92
0	e	125	14	90	96
2.9	a	88	28	76	68
2.9	b	94	18	84	72
2.9	c	119	25	83	92
2.9	d	104	34	75	80
2.9	e	80	28	74	62
4.1	a	70	58	55	54
4.1	b	72	36	67	55
4.1	c	77	45	63	59
4.1	d	69	39	64	53
4.1	e	67	47	59	52
5.9	a	37	102	27	28
5.9	b	40	64	38	31
5.9	c	21	127	14	16
5.9	d	21	114	16	16
5.9	e	27	120	18	21
8.4	a	0	-	0	0
8.4	b	1	148	1	1
8.4	c	0	-	0	0
8.4	d	1	123	1	1
8.4	e	0	-	0	0
12.0	a	0	-	0	0
12.0	b	0	-	0	0
12.0	c	0	-	0	0
12.0	d	0	-	0	0
12.0	e	0	-	0	0
17.2	a	0	-	0	0
17.2	b	0	-	0	0
17.2	c	0	-	0	0
17.2	d	0	-	0	0
17.2	e	0	-	0	0

Sampling Event #2: 10/20/2005
Test Initiation Date: 10/21/2005
Species: *Mytilus galloprovincialis*
Sample ID: GC 2

Nominal [Cu] (µg/l)	Rep	Final # Normal	# Abnormal	Percent Normal (%)	Normal Survival (%)
0	a	113	35	76	87
0	b	91	28	76	70
0	c	119	26	82	92
0	d	111	16	87	85
0	e	114	18	86	88
2.9	a	84	44	66	65
2.9	b	80	42	66	62
2.9	c	89	51	64	68
2.9	d	73	19	79	56
2.9	e	106	18	85	82
4.1	a	46	65	41	35
4.1	b	49	59	45	38
4.1	c	42	70	38	32
4.1	d	80	50	62	62
4.1	e	58	51	53	45
5.9	a	9	125	7	7
5.9	b	7	136	5	5
5.9	c	14	128	10	11
5.9	d	20	117	15	15
5.9	e	42	96	30	32
8.4	a	0	-	0	0
8.4	b	0	-	0	0
8.4	c	0	-	0	0
8.4	d	0	-	0	0
8.4	e	0	-	0	0
12.0	a	0	-	0	0
12.0	b	0	-	0	0
12.0	c	0	-	0	0
12.0	d	0	-	0	0
12.0	e	0	-	0	0

Sampling Event #2: 10/18/2005
Test Initiation Date: 10/19/2005
Species: *Mytilus galloprovincialis*
Sample ID: N

Nominal [Cu] (µg/l)	Rep	Final # Normal	# Abnormal	Percent Normal (%)	Normal Survival (%)
0	a	111	15	88	82
0	b	117	18	87	86
0	c	94	24	80	69
0	d	88	20	81	65
0	e	98	22	82	72
2.9	a	96	26	79	71
2.9	b	105	14	88	77
2.9	c	100	20	83	74
2.9	d	91	20	82	67
2.9	e	101	19	84	74
4.1	a	87	34	72	64
4.1	b	91	23	80	67
4.1	c	88	23	79	65
4.1	d	94	17	85	69
4.1	e	90	26	78	66
5.9	a	36	71	34	26
5.9	b	79	47	63	58
5.9	c	37	100	27	27
5.9	d	55	59	48	40
5.9	e	47	87	35	35
8.4	a	7	129	5	5
8.4	b	5	117	4	4
8.4	c	5	119	4	4
8.4	d	3	121	2	2
8.4	e	8	110	7	6
12.0	a	0	-	0	0
12.0	b	0	-	0	0
12.0	c	0	-	0	0
12.0	d	0	-	0	0
12.0	e	0	-	0	0
17.2	a	0	-	0	0
17.2	b	0	-	0	0
17.2	c	0	-	0	0
17.2	d	0	-	0	0
17.2	e	0	-	0	0

Sampling Event #2: 10/18/2005
Test Initiation Date: 10/19/2005
Species: *Mytilus galloprovincialis*
Sample ID: S

Nominal [Cu] (µg/l)	Rep	Final # Normal	# Abnormal	Percent Normal (%)	Normal Survival (%)
0	a	115	23	83	85
0	b	107	25	81	79
0	c	98	16	86	72
0	d	107	17	86	79
0	e	93	24	79	68
2.9	a	83	19	81	61
2.9	b	96	21	82	71
2.9	c	106	21	83	78
2.9	d	94	19	83	69
2.9	e	88	17	84	65
4.1	a	103	29	78	76
4.1	b	90	24	79	66
4.1	c	84	16	84	62
4.1	d	94	19	83	69
4.1	e	106	18	85	78
5.9	a	76	43	64	56
5.9	b	85	32	73	63
5.9	c	84	38	69	62
5.9	d	69	47	59	51
5.9	e	81	35	70	60
8.4	a	36	78	32	26
8.4	b	20	105	16	15
8.4	c	28	98	22	21
8.4	d	17	125	12	13
8.4	e	20	109	16	15
12.0	a	0	-	0	0
12.0	b	1	134	1	1
12.0	c	0	-	0	0
12.0	d	0	134	0	0
12.0	e	0	-	0	0
17.2	a	0	-	0	0
17.2	b	0	-	0	0
17.2	c	0	-	0	0
17.2	d	0	-	0	0
17.2	e	0	-	0	0
24.0	a	0	-	0	0
24.0	b	0	-	0	0
24.0	c	0	-	0	0
24.0	d	0	-	0	0
24.0	e	0	-	0	0

Sampling Event #2: 10/18/2005
Test Initiation Date: 10/19/2005
Species: *Mytilus galloprovincialis*
Sample ID: C

Nominal [Cu] (µg/l)	Rep	Final # Normal	# Abnormal	Percent Normal (%)	Normal Survival (%)
0	a	107	25	81	79
0	b	94	22	81	69
0	c	105	32	77	77
0	d	107	13	89	79
0	e	103	12	90	76
2.9	a	115	24	83	85
2.9	b	106	18	85	78
2.9	c	111	20	85	82
2.9	d	96	18	84	71
2.9	e	99	17	85	73
4.1	a	106	31	77	78
4.1	b	120	29	81	88
4.1	c	114	30	79	84
4.1	d	96	19	83	71
4.1	e	90	20	82	66
5.9	a	75	67	53	55
5.9	b	71	54	57	52
5.9	c	83	36	70	61
5.9	d	53	53	50	39
5.9	e	73	26	74	54
8.4	a	16	119	12	12
8.4	b	8	124	6	6
8.4	c	23	111	17	17
8.4	d	11	130	8	8
8.4	e	8	114	7	6
12.0	a	0	-	0	0
12.0	b	0	-	0	0
12.0	c	0	-	0	0
12.0	d	0	-	0	0
12.0	e	0	-	0	0
17.2	a	0	-	0	0
17.2	b	0	-	0	0
17.2	c	0	-	0	0
17.2	d	0	-	0	0
17.2	e	0	-	0	0

Sampling Event #2: 10/20/2005
Test Initiation Date: 10/21/2005
Species: *Mytilus galloprovincialis*
Sample ID: WL

Nominal [Cu] (µg/l)	Rep	Final # Normal	# Abnormal	Percent Normal (%)	Normal Survival (%)
0	a	95	16	86	73
0	b	93	18	84	72
0	c	95	10	90	73
0	d	101	9	92	78
2.9	a	98	30	77	75
2.9	b	100	21	83	77
2.9	c	105	17	86	81
2.9	d	94	20	82	72
4.1	a	101	16	86	78
4.1	b	107	24	82	82
4.1	c	92	18	84	71
4.1	d	90	30	75	69
5.9	a	80	34	70	62
5.9	b	96	28	77	74
5.9	c	94	20	82	72
5.9	d	100	27	79	77
8.4	a	106	24	82	82
8.4	b	101	21	83	78
8.4	c	77	20	79	59
8.4	d	86	15	85	66
12.0	a	51	64	44	39
12.0	b	42	71	37	32
12.0	c	69	31	69	53
12.0	d	70	34	67	54
17.2	a	8	127	6	6
17.2	b	12	125	9	9
17.2	c	25	105	19	19
17.2	d	30	96	0	23
24.0	a	0	-	0	0
24.0	b	0	-	0	0
24.0	c	0	-	0	0
24.0	d	0	-	0	0
35.0	a	0	-	0	0
35.0	b	0	-	0	0
35.0	c	0	-	0	0
35.0	d	0	-	0	0

Sampling Event #2: 10/20/2005
Test Initiation Date: 10/21/2005
Species: *Mytilus galloprovincialis*
Sample ID: ML

Nominal [Cu] (µg/l)	Rep	Final # Normal	# Abnormal	Percent Normal (%)	Normal Survival (%)
0	a	107	32	77	82
0	b	104	38	73	80
0	c	119	16	88	92
0	d	111	17	87	85
2.9	a	98	22	82	75
2.9	b	110	18	86	85
2.9	c	125	20	86	96
2.9	d	106	21	83	82
4.1	a	96	31	76	74
4.1	b	92	32	74	71
4.1	c	102	27	79	78
4.1	d	99	25	80	76
5.9	a	74	59	56	57
5.9	b	63	38	62	48
5.9	c	65	43	60	50
5.9	d	86	24	78	66
8.4	a	44	72	38	34
8.4	b	29	114	20	22
8.4	c	30	92	25	23
8.4	d	37	105	26	28
12.0	a	0	-	0	0
12.0	b	0	-	0	0
12.0	c	0	-	0	0
12.0	d	0	-	0	0
17.2	a	0	-	0	0
17.2	b	0	-	0	0
17.2	c	0	-	0	0
17.2	d	0	-	0	0

Sampling Event #2: 10/20/2005
Test Initiation Date: 10/21/2005
Species: *Mytilus galloprovincialis*
Sample ID: EL

Nominal [Cu] (µg/l)	Rep	Final # Normal	# Abnormal	Percent Normal (%)	Normal Survival (%)
0	a	95	14	87	73
0	b	104	17	86	80
0	c	104	11	90	80
0	d	112	13	90	86
2.9	a	111	19	85	85
2.9	b	93	17	85	72
2.9	c	100	12	89	77
2.9	d	120	14	90	92
4.1	a	92	21	81	71
4.1	b	99	34	74	76
4.1	c	95	20	83	73
4.1	d	94	17	85	72
5.9	a	54	66	45	42
5.9	b	66	52	56	51
5.9	c	71	41	63	55
5.9	d	72	44	62	55
8.4	a	12	130	8	9
8.4	b	20	115	15	15
8.4	c	7	134	5	5
8.4	d	25	105	19	19
12.0	a	0	0	0	0
12.0	b	0	0	0	0
12.0	c	0	0	0	0
12.0	d	0	0	0	0
17.2	a	0	0	0	0
17.2	b	0	0	0	0
17.2	c	0	0	0	0
17.2	d	0	0	0	0

Sampling Event #2: 10/20/2005
Test Initiation Date: 10/21/2005
Species: ***Mytilus galloprovincialis***
Sample ID: NMC

Nominal [Cu] (µg/l)	Rep	Final # Normal	# Abnormal	Percent Normal (%)	Normal Survival (%)
0	a	102	31	77	78
0	b	98	15	87	75
0	c	129	19	87	99
0	d	129	18	88	99
2.9	a	114	19	86	88
2.9	b	135	15	90	104
2.9	c	108	13	89	83
2.9	d	102	20	84	78
4.1	a	103	22	82	79
4.1	b	95	40	70	73
4.1	c	88	20	81	68
4.1	d	84	25	77	65
5.9	a	50	77	39	38
5.9	b	65	44	60	50
5.9	c	67	39	63	52
5.9	d	68	63	52	52
8.4	a	7	94	7	5
8.4	b	5	119	4	4
8.4	c	8	120	6	6
8.4	d	12	117	9	9
12.0	a	0	0	0	0
12.0	b	0	0	0	0
12.0	c	0	0	0	0
12.0	d	0	0	0	0
17.2	a	0	0	0	0
17.2	b	0	0	0	0
17.2	c	0	0	0	0
17.2	d	0	0	0	0

Sampling Event #2: 10/20/2005
Test Initiation Date: 10/21/2005
Species: ***Mytilus galloprovincialis***
Sample ID: WLC

Nominal [Cu] (µg/l)	Rep	Final # Normal	# Abnormal	Percent Normal (%)	Normal Survival (%)
0	a	106	24	82	82
0	b	115	14	89	88
0	c	107	12	90	82
0	d	102	20	84	78
0	e	116	17	87	89
2.9	a	115	21	85	88
2.9	b	107	17	86	82
2.9	c	110	22	83	85
2.9	d	114	15	88	88
2.9	e	104	16	87	80
4.1	a	105	27	80	81
4.1	b	108	21	84	83
4.1	c	105	13	89	81
4.1	d	98	10	91	75
4.1	e	108	17	86	83
5.9	a	100	18	85	77
5.9	b	111	29	79	85
5.9	c	99	23	81	76
5.9	d	114	26	81	88
5.9	e	103	30	77	79
8.4	a	84	43	66	65
8.4	b	101	39	72	78
8.4	c	99	45	69	76
8.4	d	87	39	69	67
8.4	e	92	36	72	71
12.0	a	18	72	20	14
12.0	b	26	107	20	20
12.0	c	31	96	24	24
12.0	d	30	87	26	23
12.0	e	33	104	24	25
17.2	a	2	140	1	2
17.2	b	4	130	3	3
17.2	c	1	120	1	1
17.2	d	0	-	0	0
17.2	e	3	136	2	2
24.0	a	0	-	0	0
24.0	b	0	-	0	0
24.0	c	0	-	0	0
24.0	d	0	-	0	0
24.0	e	0	-	0	0

Sampling Event #2: 10/18/2005
Test Initiation Date: 10/19/2005
Species: *Strongylocentrotus purpuratus*
Sample ID: SIO 1

Nominal [Cu] (µg/l)	Rep	Final # Normal	# Abnormal	Percent Normal (%)	Normal Survival (%)
0	a	137	13	91	82
0	b	130	8	94	77
0	c	147	10	94	88
0	d	136	9	94	81
0	e	103	13	89	61
5.9	a	171	13	93	102
5.9	b	139	8	95	83
5.9	c	130	12	92	77
5.9	d	122	9	93	73
5.9	e	109	15	88	65
8.4	a	145	13	92	86
8.4	b	161	9	95	96
8.4	c	158	18	90	94
8.4	d	119	14	89	71
8.4	e	127	6	95	76
12.0	a	120	56	68	71
12.0	b	126	29	81	75
12.0	c	131	19	87	78
12.0	d	125	14	90	74
12.0	e	152	27	85	90
17.2	a	4	145	3	2
17.2	b	20	140	13	12
17.2	c	16	137	10	10
17.2	d	45	110	29	27
17.2	e	4	152	3	2
24.0	a	0	-	0	0
24.0	b	0	-	0	0
24.0	c	0	-	0	0
24.0	d	0	-	0	0
24.0	e	0	-	0	0

Dash indicates that vial was thoroughly scanned for the presence of normal embryos.

Sampling Event #2: 10/18/2005
Test Initiation Date: 10/19/2005
Species: *Strongylocentrotus purpuratus*
Sample ID: GC 1

Nominal [Cu] (µg/l)	Rep	Final # Normal	# Abnormal	Percent Normal (%)	Normal Survival (%)
0	a	149	12	93	89
0	b	135	11	92	80
0	c	152	9	94	90
0	d	149	9	94	89
0	e	112	9	93	67
5.9	a	138	15	90	82
5.9	b	132	10	93	79
5.9	c	137	14	91	82
5.9	d	121	10	92	72
5.9	e	162	11	94	96
8.4	a	135	3	98	80
8.4	b	142	17	89	85
8.4	c	134	18	88	80
8.4	d	142	11	93	85
8.4	e	163	13	93	97
12.0	a	135	26	84	80
12.0	b	154	20	89	92
12.0	c	107	32	77	64
12.0	d	111	10	92	66
12.0	e	151	28	84	90
17.2	a	20	146	12	12
17.2	b	45	100	31	27
17.2	c	12	124	9	7
17.2	d	30	120	20	18
17.2	e	29	106	21	17
24.0	a	0	-	0	0
24.0	b	0	-	0	0
24.0	c	0	-	0	0
24.0	d	0	-	0	0
24.0	e	0	-	0	0

Sampling Event #2: 10/20/2005
Test Initiation Date: 10/21/2005
Species: *Strongylocentrotus purpuratus*
Sample ID: SIO 2

Nominal [Cu] (µg/l)	Rep	Final # Normal	# Abnormal	Percent Normal (%)	Normal Survival (%)
0	a	146	12	92	70
0	b	173	20	90	83
0	c	165	21	89	79
0	d	136	12	92	65
0	e	161	15	91	77
5.9	a	144	23	86	69
5.9	b	155	34	82	74
5.9	c	153	31	83	73
5.9	d	143	16	90	68
5.9	e	145	39	79	69
8.4	a	142	43	77	68
8.4	b	112	78	59	54
8.4	c	136	55	71	65
8.4	d	151	58	72	72
8.4	e	147	58	72	70
12.0	a	139	55	72	67
12.0	b	66	133	33	32
12.0	c	75	82	48	36
12.0	d	101	47	68	48
12.0	e	66	108	38	32
17.2	a	31	156	17	15
17.2	b	22	161	12	11
17.2	c	33	169	16	16
17.2	d	20	147	12	10
17.2	e	24	177	12	11
24.0	a	0	-	0	0
24.0	b	0	-	0	0
24.0	c	0	-	0	0
24.0	d	0	-	0	0
24.0	e	0	-	0	0

Sampling Event #2: 10/20/2005
Test Initiation Date: 10/21/2005
Species: *Strongylocentrotus purpuratus*
Sample ID: GC 2

Nominal [Cu] (µg/l)	Rep	Final # Normal	# Abnormal	Percent Normal (%)	Normal Survival (%)
0	a	197	19	91	94
0	b	173	17	91	83
0	c	179	18	91	86
0	d	161	25	87	77
0	e	176	24	88	84
5.9	a	163	17	91	78
5.9	b	145	32	82	69
5.9	c	119	17	88	57
5.9	d	169	31	85	81
5.9	e	142	32	82	68
8.4	a	169	35	83	81
8.4	b	176	23	88	84
8.4	c	124	37	77	59
8.4	d	159	33	83	76
8.4	e	159	31	84	76
12.0	a	76	138	36	36
12.0	b	99	76	57	47
12.0	c	124	64	66	59
12.0	d	95	93	51	45
12.0	e	88	92	49	42
17.2	a	36	139	21	17
17.2	b	22	108	17	11
17.2	c	12	144	8	6
17.2	d	18	165	10	9
17.2	e	14	150	9	7
24.0	a	0	173	0	0
24.0	b	0	-	0	0
24.0	c	0	-	0	0
24.0	d	0	-	0	0
24.0	e	0	-	0	0

Sampling Event #2: 10/18/2005
Test Initiation Date: 10/19/2005
Species: *Strongylocentrotus purpuratus*
Sample ID: N

Nominal [Cu] (µg/l)	Rep	Final # Normal	# Abnormal	Percent Normal (%)	Normal Survival (%)
0	a	132	7	95	79
0	b	149	10	94	89
0	c	151	18	89	90
0	d	142	7	95	85
0	e	151	15	91	90
5.9	a	150	14	91	89
5.9	b	130	14	90	77
5.9	c	130	19	87	77
5.9	d	160	7	96	95
5.9	e	146	15	91	87
8.4	a	133	18	88	79
8.4	b	175	16	92	104
8.4	c	141	12	92	84
8.4	d	143	23	86	85
8.4	e	181	16	92	108
12.0	a	105	13	89	63
12.0	b	115	22	84	68
12.0	c	113	7	94	67
12.0	d	119	41	74	71
12.0	e	132	11	92	79
17.2	a	88	50	64	52
17.2	b	104	51	67	62
17.2	c	120	42	74	71
17.2	d	68	75	48	40
17.2	e	107	52	67	64
24.0	a	7	145	5	4
24.0	b	5	139	3	3
24.0	c	11	146	7	7
24.0	d	9	130	6	5
24.0	e	6	152	4	4
35.0	a	0	140	0	0
35.0	b	0	-	0	0
35.0	c	0	-	0	0
35.0	d	0	-	0	0
35.0	e	0	-	0	0
50.0	a	0	-	0	0
50.0	b	0	-	0	0
50.0	c	0	-	0	0
50.0	d	0	-	0	0
50.0	e	0	-	0	0

Sampling Event #2: 10/18/2005
Test Initiation Date: 10/19/2005
Species: *Strongylocentrotus purpuratus*
Sample ID: S

Nominal [Cu] (µg/l)	Rep	Final # Normal	# Abnormal	Percent Normal (%)	Normal Survival (%)
0	a	135	13	91	80
0	b	129	19	87	77
0	c	178	17	91	106
0	d	148	15	91	88
0	e	143	16	90	85
5.9	a	157	13	92	93
5.9	b	139	12	92	83
5.9	c	139	18	89	83
5.9	d	117	15	89	70
5.9	e	152	16	90	90
8.4	a	139	32	81	83
8.4	b	137	18	88	82
8.4	c	138	7	95	82
8.4	d	140	10	93	83
8.4	e	152	19	89	90
12.0	a	140	14	91	83
12.0	b	143	18	89	85
12.0	c	147	18	89	88
12.0	d	143	28	84	85
12.0	e	145	9	94	86
17.2	a	50	104	32	30
17.2	b	134	25	84	80
17.2	c	121	31	80	72
17.2	d	159	25	86	95
17.2	e	121	35	78	72
24.0	a	11	141	7	7
24.0	b	54	95	36	32
24.0	c	41	109	27	24
24.0	d	42	115	27	25
24.0	e	31	125	20	18
35.0	a	0	-	0	0
35.0	b	0	-	0	0
35.0	c	0	-	0	0
35.0	d	0	-	0	0
35.0	e	0	-	0	0
50.0	a	0	-	0	0
50.0	b	0	-	0	0
50.0	c	0	-	0	0
50.0	d	0	-	0	0
50.0	e	0	-	0	0

Sampling Event #2: 10/18/2005
Test Initiation Date: 10/19/2005
Species: *Strongylocentrotus purpuratus*
Sample ID: C

Nominal [Cu] (µg/l)	Rep	Final # Normal	# Abnormal	Percent Normal (%)	Normal Survival (%)
0	a	145	2	99	86
0	b	149	11	93	89
0	c	149	8	95	89
0	d	142	9	94	85
0	e	145	11	93	86
5.9	a	143	13	92	85
5.9	b	142	16	90	85
5.9	c	110	15	88	65
5.9	d	135	14	91	80
5.9	e	160	9	95	95
8.4	a	139	13	91	83
8.4	b	160	12	93	95
8.4	c	143	13	92	85
8.4	d	128	13	91	76
8.4	e	139	13	91	83
12.0	a	167	16	91	99
12.0	b	149	8	95	89
12.0	c	111	10	92	66
12.0	d	121	17	88	72
12.0	e	149	16	90	89
17.2	a	146	15	91	87
17.2	b	119	27	82	71
17.2	c	126	26	83	75
17.2	d	132	21	86	79
17.2	e	142	15	90	85
24.0	a	33	114	22	20
24.0	b	49	105	32	29
24.0	c	31	127	20	18
24.0	d	16	148	10	10
24.0	e	39	106	27	23
35.0	a	0	-	0	0
35.0	b	0	-	0	0
35.0	c	0	-	0	0
35.0	d	0	-	0	0
35.0	e	0	-	0	0
50.0	a	0	-	0	0
50.0	b	0	-	0	0
50.0	c	0	-	0	0
50.0	d	0	-	0	0
50.0	e	0	-	0	0

Sampling Event #2: 10/20/2005
Test Initiation Date: 10/21/2005
Species: *Strongylocentrotus purpuratus*
Sample ID: WL

Nominal [Cu] (µg/l)	Rep	Final # Normal	# Abnormal	Percent Normal (%)	Normal Survival (%)
0	a	120	48	71	57
0	b	129	58	69	62
0	c	156	67	70	75
0	d	138	72	66	66
0	e	155	45	78	74
5.9	a	140	58	71	67
5.9	b	134	54	71	64
5.9	c	123	44	74	59
5.9	d	128	68	65	61
5.9	e	141	58	71	67
8.4	a	107	43	71	51
8.4	b	127	53	71	61
8.4	c	126	55	70	60
8.4	d	144	65	69	69
8.4	e	125	49	72	60
12.0	a	136	74	65	65
12.0	b	148	66	69	71
12.0	c	120	61	66	57
12.0	d	130	54	71	62
12.0	e	140	66	68	67
17.2	a	102	64	61	49
17.2	b	132	63	68	63
17.2	c	127	53	71	61
17.2	d	122	50	71	58
17.2	e	117	56	68	56
24.0	a	112	47	70	54
24.0	b	104	71	59	50
24.0	c	115	49	70	55
24.0	d	124	66	65	59
24.0	e	118	58	67	56
35.0	a	35	109	24	17
35.0	b	43	116	27	21
35.0	c	33	120	22	16
35.0	d	29	137	17	14
35.0	e	46	109	0	22
50.0	a	0	-	0	0
50.0	b	0	-	0	0
50.0	c	0	-	0	0
50.0	d	0	-	0	0
50.0	e	0	-	0	0

Sampling Event #2: 10/20/2005
Test Initiation Date: 10/21/2005
Species: *Strongylocentrotus purpuratus*
Sample ID: ML

Nominal [Cu] (µg/l)	Rep	Final # Normal	# Abnormal	Percent Normal (%)	Normal Survival (%)
0	a	174	37	82	83
0	b	231	29	89	111
0	c	144	32	82	69
0	d	138	34	80	66
0	e	162	38	81	78
5.9	a	168	42	80	80
5.9	b	178	40	82	85
5.9	c	157	42	79	75
5.9	d	163	54	75	78
5.9	e	180	40	82	86
8.4	a	164	32	84	78
8.4	b	176	37	83	84
8.4	c	155	41	79	74
8.4	d	137	37	79	66
8.4	e	145	58	71	69
12.0	a	153	42	78	73
12.0	b	142	38	79	68
12.0	c	149	42	78	71
12.0	d	165	37	82	79
12.0	e	158	46	77	76
17.2	a	147	37	80	70
17.2	b	142	48	75	68
17.2	c	130	54	71	62
17.2	d	133	59	69	64
17.2	e	137	64	68	66
24.0	a	82	146	36	39
24.0	b	14	160	8	7
24.0	c	27	146	16	13
24.0	d	84	117	42	40
24.0	e	58	129	31	28
35.0	a	0	206	0	0
35.0	b	0	-	0	0
35.0	c	0	-	0	0
35.0	d	0	-	0	0
35.0	e	0	-	0	0
50.0	a	0	185	0	0
50.0	b	0	-	0	0
50.0	c	0	-	0	0
50.0	d	0	-	0	0
50.0	e	0	-	0	0

Sampling Event #2: 10/20/2005
Test Initiation Date: 10/21/2005
Species: *Strongylocentrotus purpuratus*
Sample ID: EL

Nominal [Cu] (µg/l)	Rep	Final # Normal	# Abnormal	Percent Normal (%)	Normal Survival (%)
0	a	162	24	87	78
0	b	146	53	73	70
0	c	136	31	81	65
0	d	156	32	83	75
0	e	184	31	86	88
5.9	a	135	65	68	65
5.9	b	175	42	81	84
5.9	c	152	42	78	73
5.9	d	160	35	82	77
5.9	e	163	35	82	78
8.4	a	156	66	70	75
8.4	b	136	55	71	65
8.4	c	142	45	76	68
8.4	d	137	46	75	66
8.4	e	156	38	80	75
12.0	a	151	44	77	72
12.0	b	138	49	74	66
12.0	c	158	40	80	76
12.0	d	149	49	75	71
12.0	e	150	47	76	72
17.2	a	141	69	67	67
17.2	b	148	60	71	71
17.2	c	158	46	77	76
17.2	d	140	49	74	67
17.2	e	136	61	69	65
24.0	a	45	140	24	22
24.0	b	30	167	15	14
24.0	c	100	88	53	48
24.0	d	92	96	49	44
24.0	e	29	170	15	14
35.0	a	0	214	0	0
35.0	b	0	-	0	0
35.0	c	0	-	0	0
35.0	d	0	-	0	0
35.0	e	0	-	0	0
50.0	a	0	186	0	0
50.0	b	0	-	0	0
50.0	c	0	-	0	0
50.0	d	0	-	0	0
50.0	e	0	-	0	0

Sampling Event #2: 10/20/2005
Test Initiation Date: 10/21/2005
Species: *Strongylocentrotus purpuratus*
Sample ID: NMC

Nominal [Cu] (µg/l)	Rep	Final # Normal	# Abnormal	Percent Normal (%)	Normal Survival (%)
0	a	181	11	94	87
0	b	207	13	94	99
0	c	179	8	96	86
0	d	189	8	96	90
0	e	212	11	95	101
5.9	a	170	16	91	81
5.9	b	191	21	90	91
5.9	c	178	15	92	85
5.9	d	156	13	92	75
5.9	e	176	9	95	84
8.4	a	172	20	90	82
8.4	b	177	31	85	85
8.4	c	179	16	92	86
8.4	d	170	10	94	81
8.4	e	210	20	91	100
12.0	a	184	14	93	88
12.0	b	169	31	85	81
12.0	c	154	26	86	74
12.0	d	152	22	87	73
12.0	e	160	17	90	77
17.2	a	171	37	82	82
17.2	b	164	40	80	78
17.2	c	180	38	83	86
17.2	d	158	45	78	76
17.2	e	165	27	86	79
24.0	a	63	135	32	30
24.0	b	36	151	19	17
24.0	c	70	124	36	33
24.0	d	60	164	27	29
24.0	e	62	154	29	30
35.0	a	0	197	0	0
35.0	b	0	-	0	0
35.0	c	0	-	0	0
35.0	d	0	-	0	0
35.0	e	0	-	0	0
50.0	a	0	-	0	0
50.0	b	0	-	0	0
50.0	c	0	-	0	0
50.0	d	0	-	0	0
50.0	e	0	-	0	0

Sampling Event #2: 10/20/2005
Test Initiation Date: 10/21/2005
Species: *Strongylocentrotus purpuratus*
Sample ID: WLC

Nominal [Cu] (µg/l)	Rep	Final # Normal	# Abnormal	Percent Normal (%)	Normal Survival (%)
0	a	184	18	91	88
0	b	195	12	94	93
0	c	176	20	90	84
0	d	205	17	92	98
0	e	170	8	96	81
5.9	a	192	16	92	92
5.9	b	170	24	88	81
5.9	c	172	12	93	82
5.9	d	199	25	89	95
5.9	e	188	16	92	90
8.4	a	178	17	91	85
8.4	b	175	25	88	84
8.4	c	166	20	89	79
8.4	d	192	22	90	92
8.4	e	196	9	96	94
12.0	a	183	41	82	88
12.0	b	165	28	85	79
12.0	c	177	23	89	85
12.0	d	161	39	81	77
12.0	e	177	25	88	85
17.2	a	129	22	85	62
17.2	b	161	38	81	77
17.2	c	152	55	73	73
17.2	d	166	34	83	79
17.2	e	169	36	82	81
24.0	a	153	37	81	73
24.0	b	124	47	73	59
24.0	c	108	58	65	52
24.0	d	145	85	63	69
24.0	e	127	42	75	61
35.0	a	1	178	1	0
35.0	b	1	187	1	0
35.0	c	1	213	0	0
35.0	d	2	169	1	1
35.0	e	5	179	3	2
50.0	a	0	200	0	0
50.0	b	0	-	0	0
50.0	c	0	-	0	0
50.0	d	0	-	0	0
50.0	e	0	-	0	0

Sampling Event #3: 1/25/2006
Test Initiation Date: 1/26/2006
Species: *Mytilus galloprovincialis*
Sample ID: SIO

Nominal [Cu] (µg/l)	Rep	Final # Normal	# Abnormal	Percent Normal (%)	Normal Survival (%)
0	a	159	6	96	94
0	b	169	4	98	100
0	c	130	16	89	77
0	d	147	21	88	87
0	e	133	25	84	79
2.9	a	128	28	82	76
2.9	b	134	19	88	79
2.9	c	157	21	88	93
2.9	d	120	18	87	71
2.9	e	154	24	87	91
4.1	a	137	9	94	81
4.1	b	132	19	87	78
4.1	c	119	19	86	70
4.1	d	153	32	83	91
4.1	e	130	35	79	77
5.9	a	70	76	48	41
5.9	b	101	41	71	60
5.9	c	123	45	73	73
5.9	d	122	33	79	72
5.9	e	110	49	69	65
8.4	a	5	142	3	3
8.4	b	9	130	6	5
8.4	c	7	136	5	4
8.4	d	4	140	3	2
8.4	e	14	161	8	8
12.0	a	70	79	47	41
12.0	b	103	64	62	61
12.0	c	110	54	67	65
12.0	d	85	59	59	50
12.0	e	103	58	64	61
17.2	a	0	160	0	0
17.2	b	0	-	0	0
17.2	c	0	-	0	0
17.2	d	0	-	0	0
17.2	e	0	-	0	0

Dash indicates that vial was thoroughly scanned for the presence of normal embryos.

Sampling Event #3: 1/25/2006
Test Initiation Date: 1/26/2006
Species: *Mytilus galloprovincialis*
Sample ID: GC

Nominal [Cu] (µg/l)	Rep	Final # Normal	# Abnormal	Percent Normal (%)	Normal Survival (%)
0	a	137	13	91	81
0	b	137	13	91	81
0	c	128	13	91	76
0	d	161	16	91	95
0	e	144	16	90	85
2.9	a	141	13	92	83
2.9	b	123	13	90	73
2.9	c	176	11	94	104
2.9	d	150	12	93	89
2.9	e	143	10	93	85
4.1	a	147	14	91	87
4.1	b	145	16	90	86
4.1	c	123	21	85	73
4.1	d	137	22	86	81
4.1	e	148	11	93	88
5.9	a	131	19	87	78
5.9	b	128	20	86	76
5.9	c	144	12	92	85
5.9	d	158	19	89	93
5.9	e	122	17	88	72
8.4	a	52	100	34	31
8.4	b	38	96	28	22
8.4	c	56	105	35	33
8.4	d	76	73	51	45
8.4	e	65	92	41	38
12.0	a	0	-	0	0
12.0	b	0	-	0	0
12.0	c	0	-	0	0
17.2	a	0	150	0	0
17.2	b	0	-	0	0
17.2	c	0	-	0	0
17.2	d	0	-	0	0
17.2	e	0	-	0	0

Sampling Event #3: 1/25/2006
Test Initiation Date: 1/26/2006
Species: *Mytilus galloprovincialis*
Sample ID: SIO26

Nominal [Cu] (µg/l)	Rep	Final # Normal	# Abnormal	Percent Normal (%)	Normal Survival (%)
0	a	145	9	94	86
0	b	134	24	85	79
0	c	151	26	85	89
0	d	127	27	82	75
0	e	126	22	85	75
2.9	a	127	19	87	75
2.9	b	101	25	80	60
2.9	c	131	21	86	78
2.9	d	151	15	91	89
2.9	e	127	24	84	75
4.1	a	136	24	85	80
4.1	b	130	18	88	77
4.1	c	124	21	86	73
4.1	d	132	14	90	78
4.1	e	117	16	88	69
5.9	a	124	29	81	73
5.9	b	159	15	91	94
5.9	c	116	29	80	69
5.9	d	115	26	82	68
5.9	e	104	34	75	62
8.4	a	30	88	25	18
8.4	b	42	86	33	25
8.4	c	35	95	27	21
8.4	d	48	85	36	28
8.4	e	39	107	27	23
12.0	a	0	156	0	0
12.0	b	0	-	0	0
12.0	c	0	-	0	0
12.0	d	0	-	0	0
12.0	e	0	-	0	0
17.2	a	0	-	0	0
17.2	b	0	-	0	0
17.2	c	0	-	0	0
17.2	d	0	-	0	0
17.2	e	0	-	0	0

Sampling Event #3: 1/25/2006
Test Initiation Date: 1/26/2006
Species: *Mytilus galloprovincialis*
Sample ID: N

Nominal [Cu] (µg/l)	Rep	Final # Normal	# Abnormal	Percent Normal (%)	Normal Survival (%)
0	a	134	7	95	79
0	b	122	10	92	72
0	c	146	13	92	86
0	d	151	15	91	89
0	e	129	16	89	76
2.9	a	158	19	89	93
2.9	b	165	25	87	98
2.9	c	134	11	92	79
2.9	d	137	14	91	81
2.9	e	154	17	90	91
4.1	a	137	10	93	81
4.1	b	150	10	94	89
4.1	c	149	20	88	88
4.1	d	127	10	93	75
4.1	e	146	14	91	86
5.9	a	136	21	87	80
5.9	b	141	13	92	83
5.9	c	145	25	85	86
5.9	d	127	28	82	75
5.9	e	133	17	89	79
8.4	a	108	12	90	64
8.4	b	138	17	89	82
8.4	c	140	13	92	83
8.4	d	113	21	84	67
8.4	e	171	26	87	101
12.0	a	119	27	82	70
12.0	b	61	78	44	36
12.0	c	88	45	66	52
17.2	a	2	140	1	1
17.2	b	10	117	8	6
17.2	c	4	127	3	2
17.2	d	8	130	6	5
17.2	e	11	156	7	7
24.0	a	0	122	0	0
24.0	b	3	163	2	2
24.0	c	3	97	3	2
24.0	d	0	139	0	0
24.0	e	4	118	3	2
35.0	a	0	-	0	0
35.0	b	0	-	0	0
35.0	c	0	-	0	0
35.0	d	0	-	0	0
35.0	e	0	-	0	0

Sampling Event #3: 1/25/2006
Test Initiation Date: 1/26/2006
Species: *Mytilus galloprovincialis*
Sample ID: S

Nominal [Cu] (µg/l)	Rep	Final # Normal	# Abnormal	Percent Normal (%)	Normal Survival (%)
0	a	138	17	89	82
0	b	167	16	91	99
0	c	164	17	91	97
0	d	129	24	84	76
0	e	134	18	88	79
2.9	a	142	28	84	84
2.9	b	146	19	88	86
2.9	c	155	17	90	92
2.9	d	131	24	85	78
2.9	e	162	17	91	96
4.1	a	151	21	88	89
4.1	b	146	16	90	86
4.1	c	140	21	87	83
4.1	d	125	17	88	74
4.1	e	155	17	90	92
5.9	a	144	24	86	85
5.9	b	127	26	83	75
5.9	c	145	17	90	86
5.9	d	147	15	91	87
5.9	e	154	21	88	91
8.4	a	139	27	84	82
8.4	b	141	21	87	83
8.4	c	140	19	88	83
8.4	d	141	26	84	83
8.4	e	139	17	89	82
12.0	a	23	95	19	14
12.0	b	51	92	36	30
12.0	c	83	73	53	49
12.0	d	83	61	58	49
12.0	e	21	101	17	12
17.2	a	3	152	2	2
17.2	b	2	130	2	1
17.2	c	1	136	1	1
17.2	d	2	124	2	1
17.2	e	2	124	2	1
24.0	a	0	-	0	0
24.0	b	0	109	0	0
24.0	c	0	-	0	0
24.0	d	0	-	0	0
24.0	e	0	-	0	0
35.0	a	0	-	0	0
35.0	b	0	-	0	0
35.0	c	0	-	0	0
35.0	d	0	-	0	0
35.0	e	0	-	0	0

Sampling Event #3: 1/25/2006
Test Initiation Date: 1/26/2006
Species: *Mytilus galloprovincialis*
Sample ID: C

Nominal [Cu] (µg/l)	Rep	Final # Normal	# Abnormal	Percent Normal (%)	Normal Survival (%)
0	a	129	7	95	76
0	b	145	15	91	86
0	c	132	17	89	78
0	d	128	19	87	76
0	e	132	24	85	78
2.9	a	152	13	92	90
2.9	b	139	19	88	82
2.9	c	137	19	88	81
2.9	d	123	17	88	73
2.9	e	125	25	83	74
4.1	a	134	23	85	79
4.1	b	138	23	86	82
4.1	c	131	27	83	78
4.1	d	145	26	85	86
4.1	e	126	21	86	75
5.9	a	144	22	87	85
5.9	b	143	16	90	85
5.9	c	119	12	91	70
5.9	d	155	19	89	92
5.9	e	162	19	90	96
8.4	a	142	13	92	84
8.4	b	128	15	90	76
8.4	c	124	21	86	73
8.4	d	160	33	83	95
8.4	e	168	18	90	99
12.0	a	104	30	78	62
12.0	b	109	18	86	64
12.0	c	111	33	77	66
17.2	a	10	141	7	6
17.2	b	13	128	9	8
17.2	c	18	124	13	11
17.2	d	13	130	9	8
17.2	e	21	107	16	12
24.0	a	0	144	0	0
24.0	b	0	-	0	0
24.0	c	0	-	0	0
24.0	d	0	-	0	0
24.0	e	0	-	0	0
35.0	a	0	-	0	0
35.0	b	0	-	0	0
35.0	c	0	-	0	0
35.0	d	0	-	0	0
35.0	e	0	-	0	0

Sampling Event #3: 1/24/2006
Test Initiation Date: 1/26/2006
Species: *Mytilus galloprovincialis*
Sample ID: WL

Nominal [Cu] (µg/l)	Rep	Final # Normal	# Abnormal	Percent Normal (%)	Normal Survival (%)
0	a	145	4	97	86
0	b	145	8	95	86
0	c	165	11	94	98
0	d	132	11	92	78
0	e	147	10	94	87
2.9	a	153	18	89	91
2.9	b	142	10	93	84
2.9	c	144	12	92	85
2.9	d	167	13	93	99
2.9	e	139	16	90	82
4.1	a	136	15	90	80
4.1	b	152	19	89	90
4.1	c	124	13	91	73
4.1	d	149	14	91	88
4.1	e	152	16	90	90
5.9	a	152	17	90	90
5.9	b	125	14	90	74
5.9	c	133	13	91	79
5.9	d	168	18	90	99
5.9	e	148	21	88	88
8.4	a	148	18	89	88
8.4	b	149	20	88	88
8.4	c	164	11	94	97
8.4	d	149	15	91	88
8.4	e	138	16	90	82
12.0	a	140	6	96	83
12.0	b	136	22	86	80
12.0	c	154	10	94	91
12.0	d	147	17	90	87
12.0	e	138	20	87	82
17.2	a	151	13	92	89
17.2	b	124	10	93	73
17.2	c	134	30	82	79
17.2	d	124	23	84	73
17.2	e	138	25	85	82
24.0	a	0	155	0	0
24.0	b	0	-	0	0
24.0	c	4	141	3	2
24.0	d	6	154	4	4
24.0	e	7	163	4	4
35.0	a	0	98	0	0
35.0	b	0	-	0	0
35.0	c	0	-	0	0
35.0	d	0	-	0	0
35.0	e	0	-	0	0

Sampling Event #3: 1/25/2006
Test Initiation Date: 1/26/2006
Species: *Mytilus galloprovincialis*
Sample ID: ML

Nominal [Cu] (µg/l)	Rep	Final # Normal	# Abnormal	Percent Normal (%)	Normal Survival (%)
0	a	123	13	90	73
0	b	137	18	88	81
0	c	115	11	91	68
0	d	147	23	86	87
0	e	148	8	95	88
2.9	a	137	15	90	81
2.9	b	138	10	93	82
2.9	c	119	14	89	70
2.9	d	127	21	86	75
2.9	e	104	22	83	62
4.1	a	130	18	88	77
4.1	b	121	13	90	72
4.1	c	127	19	87	75
4.1	d	126	16	89	75
4.1	e	135	18	88	80
5.9	a	132	18	88	78
5.9	b	147	18	89	87
5.9	c	105	19	85	62
5.9	d	132	24	85	78
5.9	e	141	24	85	83
8.4	a	137	18	88	81
8.4	b	138	16	90	82
8.4	c	144	25	85	85
8.4	d	118	27	81	70
8.4	e	145	22	87	86
12.0	a	155	16	91	92
12.0	b	142	7	95	84
12.0	c	137	20	87	81
12.0	d	128	23	85	76
12.0	e	136	22	86	80
17.2	a	148	36	80	88
17.2	b	134	25	84	79
17.2	c	119	33	78	70
17.2	d	116	24	83	69
17.2	e	142	30	83	84
24.0	a	7	146	5	4
24.0	b	7	123	5	4
24.0	c	29	105	22	17
24.0	d	24	130	16	14
24.0	e	23	14	62	14
35.0	a	0	-	0	0
35.0	b	0	147	0	0
35.0	c	0	-	0	0
35.0	d	0	-	0	0
35.0	e	0	-	0	0

Sampling Event #3: 1/25/2006
Test Initiation Date: 1/26/2006
Species: *Mytilus galloprovincialis*
Sample ID: EL

Nominal [Cu] (µg/l)	Rep	Final # Normal	# Abnormal	Percent Normal (%)	Normal Survival (%)
0	a	159	9	95	94
0	b	146	13	92	86
0	c	153	16	91	91
0	d	140	7	95	83
0	e	240	26	90	142
2.9	a	149	21	88	88
2.9	b	146	13	92	86
2.9	c	122	21	85	72
2.9	d	137	10	93	81
2.9	e	166	15	92	98
4.1	a	129	10	93	76
4.1	b	139	16	90	82
4.1	c	145	15	91	86
4.1	d	135	7	95	80
4.1	e	132	14	90	78
5.9	a	233	30	89	138
5.9	b	145	8	95	86
5.9	c	128	15	90	76
5.9	d	168	17	91	99
5.9	e	128	23	85	76
8.4	a	115	11	91	68
8.4	b	167	14	92	99
8.4	c	127	20	86	75
8.4	d	119	18	87	70
8.4	e	116	19	86	69
12.0	a	72	64	53	43
12.0	b	103	58	64	61
12.0	c	130	33	80	77
12.0	d	108	27	80	64
12.0	e	123	38	76	73
17.2	a	0	130	0	0
17.2	b	0	-	0	0
17.2	c	1	117	1	1
17.2	d	4	132	3	2
17.2	e	3	116	3	2
24.0	a	0	113	0	0
24.0	b	0	-	0	0
24.0	c	0	-	0	0
24.0	d	0	-	0	0
24.0	e	0	-	0	0
35.0	a	0	-	0	0
35.0	b	0	-	0	0
35.0	c	0	-	0	0
35.0	d	0	-	0	0
35.0	e	0	-	0	0

Sampling Event #3: 1/25/2006
Test Initiation Date: 1/26/2006
Species: *Mytilus galloprovincialis*
Sample ID: NMC

Nominal [Cu] (µg/l)	Rep	Final # Normal	# Abnormal	Percent Normal (%)	Normal Survival (%)
0	a	136	10	93	80
0	b	122	17	88	72
0	c	110	22	83	65
0	d	144	19	88	85
0	e	146	20	88	86
2.9	a	149	31	83	88
2.9	b	128	16	89	76
2.9	c	165	20	89	98
2.9	d	134	22	86	79
2.9	e	143	28	84	85
4.1	a	120	10	92	71
4.1	b	131	21	86	78
4.1	c	122	16	88	72
4.1	d	156	22	88	92
4.1	e	148	33	82	88
5.9	a	120	23	84	71
5.9	b	115	23	83	68
5.9	c	147	16	90	87
5.9	d	120	12	91	71
5.9	e	156	28	85	92
8.4	a	145	13	92	86
8.4	b	147	15	91	87
8.4	c	139	22	86	82
8.4	d	139	21	87	82
8.4	e	144	26	85	85
12.0	a	98	48	67	58
12.0	b	105	28	79	62
12.0	c	117	41	74	69
12.0	d	124	39	76	73
12.0	e	109	51	68	64
17.2	a	8	143	5	5
17.2	b	2	150	1	1
17.2	c	9	127	7	5
17.2	d	8	134	6	5
17.2	e	12	131	8	7
24.0	a	0	-	0	0
24.0	b	0	-	0	0
24.0	c	0	-	0	0
24.0	d	0	-	0	0
24.0	e	0	-	0	0
35.0	a	0	-	0	0
35.0	b	0	-	0	0
35.0	c	0	-	0	0
35.0	d	0	-	0	0
35.0	e	0	-	0	0

Sampling Event #3: 1/24/2006
Test Initiation Date: 1/26/2006
Species: *Mytilus galloprovincialis*
Sample ID: WLC

Nominal [Cu] (µg/l)	Rep	Final # Normal	# Abnormal	Percent Normal (%)	Normal Survival (%)
0	a	151	5	97	89
0	b	153	20	88	91
0	c	145	12	92	86
0	d	150	12	93	89
0	e	136	8	94	80
2.9	a	171	22	89	101
2.9	b	132	19	87	78
2.9	c	141	19	88	83
2.9	d	152	16	90	90
2.9	e	146	22	87	86
4.1	a	124	17	88	73
4.1	b	132	16	89	78
4.1	c	153	18	89	91
4.1	d	139	16	90	82
4.1	e	151	18	89	89
5.9	a	151	15	91	89
5.9	b	121	16	88	72
5.9	c	148	25	86	88
5.9	d	130	21	86	77
5.9	e	146	18	89	86
8.4	a	179	8	96	106
8.4	b	118	15	89	70
8.4	c	136	14	91	80
8.4	d	118	37	76	70
8.4	e	108	16	87	64
12.0	a	156	10	94	92
12.0	b	151	32	83	89
12.0	c	137	19	88	81
12.0	d	144	18	89	85
12.0	e	141	15	90	83
17.2	a	143	9	94	85
17.2	b	124	14	90	73
17.2	c	145	14	91	86
17.2	d	137	20	87	81
17.2	e	141	21	87	83
24.0	a	0	157	0	0
24.0	b	3	126	2	2
24.0	c	2	141	1	1
24.0	d	5	140	3	3
24.0	e	2	120	2	1
35.0	a	0	132	0	0
35.0	b	0	-	0	0
35.0	c	0	-	0	0
35.0	d	0	-	0	0
35.0	e	0	-	0	0

Sampling Event #4: 5/16/2006
Test Initiation Date: 5/17/2006
Species: *Mytilus galloprovincialis*
Sample ID: SIO 1

Nominal [Cu] (µg/l)	Rep	Final # Normal	# Abnormal	Percent Normal (%)	Normal Survival (%)
0	a	111	32	78	74
0	b	120	16	88	79
0	c	119	29	80	79
0	d	122	28	81	81
0	e	112	24	82	74
2.9	a	122	29	81	81
2.9	b	139	35	80	92
2.9	c	125	32	80	83
2.9	d	131	32	80	87
2.9	e	103	36	74	68
4.1	a	93	61	60	62
4.1	b	86	44	66	57
4.1	c	82	45	65	54
4.1	d	105	32	77	70
4.1	e	113	30	79	75
5.9	a	31	122	20	21
5.9	b	36	113	24	24
5.9	c	34	118	22	23
5.9	d	16	118	12	11
5.9	e	26	122	18	17
8.4	a	0	-	0	0
8.4	b	0	-	0	0
8.4	c	0	-	0	0
8.4	d	0	-	0	0
8.4	e	0	-	0	0
12.0	a	0	-	0	0
12.0	b	0	-	0	0
12.0	c	0	-	0	0
12.0	d	0	-	0	0
12.0	e	0	-	0	0

Dash indicates that vial was thoroughly scanned for the presence of normal embryos.

Sampling Event #4: 5/16/2006
Test Initiation Date: 5/17/2006
Species: *Mytilus galloprovincialis*
Sample ID: GC 1

Nominal [Cu] (µg/l)	Rep	Final # Normal	# Abnormal	Percent Normal (%)	Normal Survival (%)
0	a	132	10	93	87
0	b	111	31	78	74
0	c	106	23	82	70
0	d	106	26	80	70
0	e	101	29	78	67
2.9	a	107	46	70	71
2.9	b	110	29	79	73
2.9	c	110	37	75	73
2.9	d	119	28	81	79
2.9	e	115	23	83	76
4.1	a	95	33	74	63
4.1	b	135	24	85	89
4.1	c	119	31	79	79
4.1	d	103	28	79	68
4.1	e	109	35	76	72
5.9	a	73	84	46	48
5.9	b	83	67	55	55
5.9	c	95	42	69	63
5.9	d	76	46	62	50
5.9	e	82	64	56	54
8.4	a	12	109	10	8
8.4	b	2	118	2	1
8.4	c	2	124	2	1
8.4	d	1	125	1	1
8.4	e	2	117	2	1
12.0	a	0	-	0	0
12.0	b	0	-	0	0
12.0	c	0	-	0	0
12.0	d	0	-	0	0
12.0	e	0	-	0	0
17.2	a	0	-	0	0
17.2	b	0	-	0	0
17.2	c	0	-	0	0
17.2	d	0	-	0	0
17.2	e	0	-	0	0

Sampling Event #4: 5/17/2006
Test Initiation Date: 5/18/2006
Species: *Mytilus galloprovincialis*
Sample ID: SIO 2

Nominal [Cu] (µg/l)	Rep	Final # Normal	# Abnormal	Percent Normal (%)	Normal Survival (%)
0	a	190	6	97	98
0	b	182	6	97	94
0	c	174	3	98	90
0	d	191	10	95	98
0	e	160	8	95	82
2.9	a	189	16	92	97
2.9	b	162	15	92	84
2.9	c	162	8	95	84
2.9	d	186	21	90	96
2.9	e	169	14	92	87
4.1	a	140	43	77	72
4.1	b	116	57	67	60
4.1	c	153	36	81	79
4.1	d	152	24	86	78
4.1	e	154	25	86	79
5.9	a	26	146	15	13
5.9	b	26	158	14	13
5.9	c	44	114	28	23
5.9	d	25	144	15	13
5.9	e	33	140	19	17
8.4	a	0	-	0	0
8.4	b	0	-	0	0
8.4	c	0	-	0	0
8.4	d	0	-	0	0
8.4	e	0	-	0	0
12.0	a	0	-	0	0
12.0	b	0	-	0	0
12.0	c	0	-	0	0
12.0	d	0	-	0	0
12.0	e	0	-	0	0

Sampling Event #4: 5/17/2006
Test Initiation Date: 5/18/2006
Species: *Mytilus galloprovincialis*
Sample ID: GC 2

Nominal [Cu] (µg/l)	Rep	Final # Normal	# Abnormal	Percent Normal (%)	Normal Survival (%)
0	a	178	6	97	92
0	b	180	5	97	93
0	c	164	2	99	85
0	d	163	4	98	84
0	e	178	2	99	92
2.9	a	175	7	96	90
2.9	b	169	2	99	87
2.9	c	169	6	97	87
2.9	d	160	7	96	82
2.9	e	212	4	98	109
4.1	a	173	14	93	89
4.1	b	166	15	92	86
4.1	c	180	7	96	93
4.1	d	170	10	94	88
4.1	e	177	12	94	91
5.9	a	164	34	83	85
5.9	b	157	36	81	81
5.9	c	122	36	77	63
5.9	d	142	26	85	73
5.9	e	142	42	77	73
8.4	a	7	192	4	4
8.4	b	12	149	7	6
8.4	c	32	140	19	16
8.4	d	17	189	8	9
8.4	e	22	181	11	11
12.0	a	0	189	0	0
12.0	b	0	-	0	0
12.0	c	0	-	0	0
12.0	d	0	-	0	0
12.0	e	0	-	0	0
17.2	a	0	-	0	0
17.2	b	0	-	0	0
17.2	c	0	-	0	0
17.2	d	0	-	0	0
17.2	e	0	-	0	0

Sampling Event #4: 5/16/2006
Test Initiation Date: 5/17/2006
Species: *Mytilus galloprovincialis*
Sample ID: N

Nominal [Cu] (µg/l)	Rep	Final # Normal	# Abnormal	Percent Normal (%)	Normal Survival (%)
0	a	118	9	93	78
0	b	126	16	89	83
0	c	128	11	92	85
0	d	121	18	87	80
0	e	127	26	83	84
2.9	a	112	21	84	74
2.9	b	111	20	85	74
2.9	c	111	18	86	74
2.9	d	103	13	89	68
2.9	e	134	19	88	89
4.1	a	143	23	86	95
4.1	b	114	13	90	75
4.1	c	106	19	85	70
4.1	d	122	24	84	81
4.1	e	115	34	77	76
5.9	a	120	23	84	79
5.9	b	95	15	86	63
5.9	c	116	11	91	77
5.9	d	120	20	86	79
5.9	e	116	22	84	77
8.4	a	48	72	40	32
8.4	b	59	68	46	39
8.4	c	49	70	41	32
8.4	d	49	62	44	32
8.4	e	56	66	46	37
12.0	a	16	105	13	11
12.0	b	4	127	3	3
12.0	c	3	119	2	2
12.0	d	4	121	3	3
12.0	e	3	118	2	2
17.2	a	0	-	0	0
17.2	b	0	-	0	0
17.2	c	0	-	0	0
17.2	d	0	-	0	0
17.2	e	0	-	0	0
24.0	a	0	-	0	0
24.0	b	0	-	0	0
24.0	c	0	-	0	0
24.0	d	0	-	0	0
24.0	e	0	-	0	0

Sampling Event #4: 5/16/2006
Test Initiation Date: 5/17/2006
Species: *Mytilus galloprovincialis*
Sample ID: S

Nominal [Cu] (µg/l)	Rep	Final # Normal	# Abnormal	Percent Normal (%)	Normal Survival (%)
0	a	116	9	93	77
0	b	107	14	88	71
0	c	120	16	88	79
0	d	126	23	85	83
0	e	103	16	87	68
2.9	a	131	18	88	87
2.9	b	108	21	84	72
2.9	c	115	14	89	76
2.9	d	124	20	86	82
2.9	e	116	18	87	77
4.1	a	109	13	89	72
4.1	b	93	22	81	62
4.1	c	110	22	83	73
4.1	d	98	27	78	65
4.1	e	125	20	86	83
5.9	a	120	18	87	79
5.9	b	115	16	88	76
5.9	c	116	22	84	77
5.9	d	117	8	94	77
5.9	e	116	13	90	77
8.4	a	129	10	93	85
8.4	b	108	25	81	72
8.4	c	109	13	89	72
8.4	d	118	17	87	78
8.4	e	106	15	88	70
12.0	a	40	83	33	26
12.0	b	43	128	25	28
12.0	c	28	91	24	19
12.0	d	30	78	28	20
12.0	e	41	68	38	27
17.2	a	0	-	0	0
17.2	b	0	-	0	0
17.2	c	0	-	0	0
17.2	d	0	-	0	0
17.2	e	0	-	0	0
24.0	a	0	-	0	0
24.0	b	0	-	0	0
24.0	c	0	-	0	0
24.0	d	0	-	0	0
24.0	e	0	-	0	0

Sampling Event #4: 5/16/2006
Test Initiation Date: 5/17/2006
Species: *Mytilus galloprovincialis*
Sample ID: C

Nominal [Cu] (µg/l)	Rep	Final # Normal	# Abnormal	Percent Normal (%)	Normal Survival (%)
0	a	132	31	81	87
0	b	105	22	83	70
0	c	120	26	82	79
0	d	115	22	84	76
0	e	124	26	83	82
2.9	a	121	23	84	80
2.9	b	105	24	81	70
2.9	c	102	34	75	68
2.9	d	103	19	84	68
2.9	e	119	15	89	79
4.1	a	114	22	84	75
4.1	b	124	26	83	82
4.1	c	127	28	82	84
4.1	d	104	25	81	69
4.1	e	112	15	88	74
5.9	a	108	34	76	72
5.9	b	103	19	84	68
5.9	c	113	25	82	75
5.9	d	128	19	87	85
5.9	e	143	34	81	95
8.4	a	93	49	65	62
8.4	b	84	57	60	56
8.4	c	78	63	55	52
8.4	d	87	52	63	58
8.4	e	87	42	67	58
12.0	a	8	109	7	5
12.0	b	7	117	6	5
12.0	c	19	115	14	13
12.0	d	29	86	25	19
12.0	e	10	140	7	7
17.2	a	0	-	0	0
17.2	b	0	-	0	0
17.2	c	0	-	0	0
17.2	d	0	-	0	0
17.2	e	0	-	0	0
24.0	a	0	-	0	0
24.0	b	0	-	0	0
24.0	c	0	-	0	0
24.0	d	0	-	0	0
24.0	e	0	-	0	0

Sampling Event #4: 5/17/2006
Test Initiation Date: 5/18/2006
Species: *Mytilus galloprovincialis*
Sample ID: WL

Nominal [Cu] (µg/l)	Rep	Final # Normal	# Abnormal	Percent Normal (%)	Normal Survival (%)
0	a	169	2	99	87
0	b	215	3	99	111
0	c	160	3	98	82
0	d	168	8	95	87
0	e	203	6	97	105
2.9	a	192	6	97	99
2.9	b	130	4	97	67
2.9	c	166	6	97	86
2.9	d	192	6	97	99
2.9	e	166	4	98	86
4.1	a	170	4	98	88
4.1	b	167	2	99	86
4.1	c	188	10	95	97
4.1	d	185	6	97	95
4.1	e	174	7	96	90
5.9	a	184	6	97	95
5.9	b	174	11	94	90
5.9	c	186	4	98	96
5.9	d	197	7	97	102
5.9	e	184	5	97	95
8.4	a	179	5	97	92
8.4	b	167	14	92	86
8.4	c	148	8	95	76
8.4	d	147	6	96	76
8.4	e	168	7	96	87
12.0	a	155	27	85	80
12.0	b	154	11	93	79
12.0	c	152	13	92	78
12.0	d	183	22	89	94
12.0	e	165	9	95	85
17.2	a	11	145	7	6
17.2	b	11	156	7	6
17.2	c	32	129	20	16
17.2	d	35	135	21	18
17.2	e	42	94	31	22
24.0	a	0	-	0	0
24.0	b	0	-	0	0
24.0	c	0	-	0	0
24.0	d	0	-	0	0
24.0	e	0	-	0	0
35.0	a	0	-	0	0
35.0	b	0	-	0	0
35.0	c	0	-	0	0
35.0	d	0	-	0	0
35.0	e	0	-	0	0

Sampling Event #4: 5/17/2006
Test Initiation Date: 5/18/2006
Species: *Mytilus galloprovincialis*
Sample ID: ML

Nominal [Cu] (µg/l)	Rep	Final # Normal	# Abnormal	Percent Normal (%)	Normal Survival (%)
0	a	202	9	96	104
0	b	162	7	96	84
0	c	191	8	96	98
0	d	168	8	95	87
0	e	171	12	93	88
2.9	a	173	5	97	89
2.9	b	190	10	95	98
2.9	c	169	5	97	87
2.9	d	160	6	96	82
2.9	e	196	8	96	101
4.1	a	159	9	95	82
4.1	b	163	15	92	84
4.1	c	203	11	95	105
4.1	d	174	10	95	90
4.1	e	177	13	93	91
5.9	a	160	11	94	82
5.9	b	179	10	95	92
5.9	c	175	10	95	90
5.9	d	180	10	95	93
5.9	e	147	12	92	76
8.4	a	151	25	86	78
8.4	b	144	36	80	74
8.4	c	154	25	86	79
8.4	d	147	23	86	76
8.4	e	157	26	86	81
12.0	a	22	140	14	11
12.0	b	21	155	12	11
12.0	c	17	150	10	9
12.0	d	29	135	18	15
12.0	e	25	155	14	13
17.2	a	0	208	0	0
17.2	b	0	-	0	0
17.2	c	0	-	0	0
17.2	d	0	-	0	0
17.2	e	0	-	0	0

Sampling Event #4: 5/16/2006
Test Initiation Date: 5/17/2006
Species: *Mytilus galloprovincialis*
Sample ID: EL

Nominal [Cu] (µg/l)	Rep	Final # Normal	# Abnormal	Percent Normal (%)	Normal Survival (%)
0	a	116	17	87	77
0	b	118	18	87	78
0	c	102	11	90	68
0	d	122	14	90	81
0	e	115	12	91	76
2.9	a	126	25	83	83
2.9	b	129	21	86	85
2.9	c	107	18	86	71
2.9	d	124	20	86	82
2.9	e	113	14	89	75
4.1	a	126	25	83	83
4.1	b	118	16	88	78
4.1	c	108	13	89	72
4.1	d	118	18	87	78
4.1	e	107	15	88	71
5.9	a	116	16	88	77
5.9	b	124	13	91	82
5.9	c	130	24	84	86
5.9	d	121	26	82	80
5.9	e	122	19	87	81
8.4	a	155	120	56	103
8.4	b	67	72	48	44
8.4	c	52	51	50	34
8.4	d	80	45	64	53
8.4	e	102	38	73	68
12.0	a	29	103	22	19
12.0	b	11	127	8	7
12.0	c	2	79	2	1
12.0	d	17	104	14	11
12.0	e	7	109	6	5
17.2	a	0	-	0	0
17.2	b	0	-	0	0
17.2	c	0	-	0	0
17.2	d	0	-	0	0
17.2	e	0	-	0	0

Sampling Event #4: 5/17/2006
Test Initiation Date: 5/18/2006
Species: *Mytilus galloprovincialis*
Sample ID: NMC

Nominal [Cu] (µg/l)	Rep	Final # Normal	# Abnormal	Percent Normal (%)	Normal Survival (%)
0	a	194	8	96	100
0	b	163	3	98	84
0	c	165	5	97	85
0	d	189	5	97	97
0	e	209	6	97	108
2.9	a	155	8	95	80
2.9	b	185	7	96	95
2.9	c	137	10	93	71
2.9	d	161	13	93	83
2.9	e	201	12	94	104
4.1	a	179	10	95	92
4.1	b	166	4	98	86
4.1	c	161	7	96	83
4.1	d	173	3	98	89
4.1	e	165	10	94	85
5.9	a	192	11	95	99
5.9	b	156	14	92	80
5.9	c	151	14	92	78
5.9	d	182	20	90	94
5.9	e	176	13	93	91
8.4	a	63	117	35	32
8.4	b	81	96	46	42
8.4	c	76	106	42	39
8.4	d	95	96	50	49
8.4	e	107	84	56	55
12.0	a	0	190	0	0
12.0	b	0	-	0	0
12.0	c	0	-	0	0
12.0	d	0	-	0	0
12.0	e	0	-	0	0
17.2	a	0	-	0	0
17.2	b	0	-	0	0
17.2	c	0	-	0	0
17.2	d	0	-	0	0
17.2	e	0	-	0	0

Sampling Event #4: 5/17/2006
Test Initiation Date: 5/18/2006
Species: *Mytilus galloprovincialis*
Sample ID: WLC

Nominal [Cu] (µg/l)	Rep	Final # Normal	# Abnormal	Percent Normal (%)	Normal Survival (%)
0	a	181	5	97	93
0	b	208	10	95	107
0	c	189	7	96	97
0	d	169	5	97	87
0	e	186	5	97	96
2.9	a	181	8	96	93
2.9	b	186	5	97	96
2.9	c	162	5	97	84
2.9	d	173	6	97	89
2.9	e	175	5	97	90
4.1	a	185	4	98	95
4.1	b	169	2	99	87
4.1	c	171	7	96	88
4.1	d	148	11	93	76
4.1	e	156	3	98	80
5.9	a	149	9	94	77
5.9	b	179	4	98	92
5.9	c	173	10	95	89
5.9	d	179	7	96	92
5.9	e	175	6	97	90
8.4	a	169	2	99	87
8.4	b	162	8	95	84
8.4	c	169	4	98	87
8.4	d	192	8	96	99
8.4	e	180	9	95	93
12.0	a	154	36	81	79
12.0	b	141	36	80	73
12.0	c	147	33	82	76
12.0	d	164	26	86	85
12.0	e	165	27	86	85
17.2	a	12	170	7	6
17.2	b	3	161	2	2
17.2	c	8	152	5	4
17.2	d	15	155	9	8
17.2	e	12	161	7	6
24.0	a	0	-	0	0
24.0	b	0	-	0	0
24.0	c	0	-	0	0
24.0	d	0	-	0	0
24.0	e	0	-	0	0

Sampling Event #4: 5/16/2006
Test Initiation Date: 5/17/2006
Species: *Crassostrea gigas*
Sample ID: SIO 1

Nominal [Cu] (µg/l)	Rep	Final # Normal	# Abnormal	Percent Normal (%)	Normal Survival (%)
0	a	79	7	92	54
0	b	93	12	89	63
0	c	68	3	96	46
0	d	81	13	86	55
0	e	88	10	90	60
2.9	a	85	8	91	58
2.9	b	88	9	91	60
2.9	c	96	10	91	65
2.9	d	77	14	85	52
2.9	e	75	6	93	51
4.1	a	92	18	84	63
4.1	b	79	17	82	54
4.1	c	87	14	86	59
4.1	d	68	11	86	46
4.1	e	83	11	88	56
5.9	a	51	41	55	35
5.9	b	56	30	65	38
5.9	c	47	43	52	32
5.9	d	64	44	59	44
5.9	e	59	51	54	40
8.4	a	18	117	13	12
8.4	b	11	107	9	7
8.4	c	19	99	16	13
8.4	d	10	100	9	7
8.4	e	10	90	10	7
12.0	a	2	103	0	1
12.0	b	0	-	0	0
12.0	c	0	-	0	0
12.0	d	0	-	0	0
12.0	e	0	-	0	0
17.2	a	0	-	0	0
17.2	b	0	-	0	0
17.2	c	0	-	0	0
17.2	d	0	-	0	0
17.2	e	0	-	0	0

Sampling Event #4: 5/16/2006
Test Initiation Date: 5/17/2006
Species: *Crassostrea gigas*
Sample ID: GC 1

Nominal [Cu] (µg/l)	Rep	Final # Normal	# Abnormal	Percent Normal (%)	Normal Survival (%)
0	a	74	6	93	50
0	b	96	10	91	65
0	c	75	7	91	51
0	d	79	6	93	54
0	e	94	12	89	64
2.9	a	86	6	93	59
2.9	b	100	2	98	68
2.9	c	72	9	89	49
2.9	d	80	6	93	54
2.9	e	75	4	95	51
4.1	a	79	9	90	54
4.1	b	90	5	95	61
4.1	c	62	8	89	42
4.1	d	74	13	85	50
4.1	e	104	6	95	71
5.9	a	83	24	78	56
5.9	b	54	12	82	37
5.9	c	70	15	82	48
5.9	d	80	20	80	54
5.9	e	70	19	79	48
8.4	a	41	78	34	28
8.4	b	21	52	29	14
8.4	c	25	64	28	17
8.4	d	36	70	34	24
8.4	e	36	43	46	24
12.0	a	0	-	0	0
12.0	b	0	-	0	0
12.0	c	0	-	0	0
12.0	d	0	-	0	0
12.0	e	0	-	0	0
17.2	a	0	-	0	0
17.2	b	0	-	0	0
17.2	c	0	-	0	0
17.2	d	0	-	0	0
17.2	e	0	-	0	0

Dash indicates that vial was thoroughly scanned for the presence of normal embryos.

Sampling Event #4: 5/17/2006
Test Initiation Date: 5/18/2006
Species: *Crassostrea gigas*
Sample ID: SIO 2

Nominal [Cu] (µg/l)	Rep	Final # Normal	# Abnormal	Percent Normal (%)	Normal Survival (%)
0	a	149	12	93	80
0	b	167	10	94	89
0	c	181	11	94	97
0	d	162	17	91	87
0	e	154	16	91	82
2.9	a	137	15	90	73
2.9	b	166	16	91	89
2.9	c	171	25	87	91
2.9	d	182	20	90	97
2.9	e	145	27	84	78
4.1	a	155	30	84	83
4.1	b	177	22	89	95
4.1	c	158	19	89	84
4.1	d	168	28	86	90
4.1	e	185	15	93	99
5.9	a	141	23	86	75
5.9	b	133	27	83	71
5.9	c	119	34	78	64
5.9	d	115	35	77	61
5.9	e	147	40	79	79
8.4	a	119	62	66	64
8.4	b	117	92	56	63
8.4	c	74	75	50	40
8.4	d	97	94	51	52
8.4	e	95	102	48	51
12.0	a	32	126	20	17
12.0	b	25	138	15	13
12.0	c	25	146	15	13
12.0	d	34	116	23	18
12.0	e	27	127	18	14
17.2	a	0	-	0	0
17.2	b	0	-	0	0
17.2	c	6	162	4	3
17.2	d	0	-	0	0
17.2	e	3	195	2	2

Sampling Event #4: 5/17/2006
Test Initiation Date: 5/18/2006
Species: *Crassostrea gigas*
Sample ID: GC 2

Nominal [Cu] (µg/l)	Rep	Final # Normal	# Abnormal	Percent Normal (%)	Normal Survival (%)
0	a	164	14	92	88
0	b	150	8	95	80
0	c	173	8	96	93
0	d	162	9	95	87
0	e	153	9	94	82
2.9	a	161	9	95	86
2.9	b	112	6	95	60
2.9	c	150	14	91	80
2.9	d	144	12	92	77
2.9	e	121	6	95	65
4.1	a	130	10	93	70
4.1	b	163	17	91	87
4.1	c	159	21	88	85
4.1	d	158	12	93	84
4.1	e	189	15	93	101
5.9	a	158	19	89	84
5.9	b	197	19	91	105
5.9	c	184	16	92	98
5.9	d	143	20	88	76
5.9	e	146	13	92	78
8.4	a	178	31	85	95
8.4	b	156	22	88	83
8.4	c	119	30	80	64
8.4	d	163	20	89	87
8.4	e	142	35	80	76
12.0	a	69	102	40	37
12.0	b	63	120	34	34
12.0	c	46	112	29	25
12.0	d	61	114	35	33
12.0	e	50	127	28	27
17.2	a	0	136	0	0
17.2	b	4	179	2	2
17.2	c	0	-	0	0
17.2	d	0	-	0	0
17.2	e	1	178	1	1

Sampling Event #4: 5/16/2006
Test Initiation Date: 5/17/2006
Species: *Crassostrea gigas*
Sample ID: N

Nominal [Cu] (µg/l)	Rep	Final # Normal	# Abnormal	Percent Normal (%)	Normal Survival (%)
0	a	78	17	82	53
0	b	81	16	84	55
0	c	80	9	90	54
0	d	105	11	91	71
0	e	79	14	85	54
2.9	a	88	10	90	60
2.9	b	78	14	85	53
2.9	c	102	11	90	69
2.9	d	78	17	82	53
2.9	e	79	14	85	54
4.1	a	95	18	84	65
4.1	b	67	15	82	46
4.1	c	81	12	87	55
4.1	d	89	16	85	61
4.1	e	60	17	78	41
5.9	a	62	18	78	42
5.9	b	74	10	88	50
5.9	c	65	16	80	44
5.9	d	79	10	89	54
5.9	e	64	9	88	44
8.4	a	49	21	70	33
8.4	b	58	29	67	39
8.4	c	53	17	76	36
8.4	d	63	17	79	43
8.4	e	44	14	76	30
12.0	a	31	45	41	21
12.0	b	25	43	37	17
12.0	c	32	30	52	22
12.0	d	41	35	54	28
12.0	e	39	36	52	27
17.2	a	0	97	0	0
17.2	b	0	-	0	0
17.2	c	0	-	0	0
17.2	d	0	-	0	0
17.2	e	0	-	0	0
24.0	a	0	-	0	0
24.0	b	0	-	0	0
24.0	c	0	-	0	0
24.0	d	0	-	0	0
24.0	e	0	-	0	0

Sampling Event #4: 5/16/2006
Test Initiation Date: 5/17/2006
Species: *Crassostrea gigas*
Sample ID: S

Nominal [Cu] (µg/l)	Rep	Final # Normal	# Abnormal	Percent Normal (%)	Normal Survival (%)
0	a	108	10	92	73
0	b	121	3	98	82
0	c	160	4	98	109
0	d	124	3	98	84
0	e	116	2	98	79
2.9	a	121	4	97	82
2.9	b	136	7	95	93
2.9	c	115	9	93	78
2.9	d	115	4	97	78
2.9	e	120	6	95	82
4.1	a	145	9	94	99
4.1	b	113	6	95	77
4.1	c	111	8	93	76
4.1	d	120	7	94	82
4.1	e	125	10	93	85
5.9	a	101	5	95	69
5.9	b	140	6	96	95
5.9	c	129	5	96	88
5.9	d	117	7	94	80
5.9	e	120	9	93	82
8.4	a	100	12	89	68
8.4	b	127	13	91	86
8.4	c	353	17	95	240
8.4	d	133	6	96	90
8.4	e	129	18	88	88
12.0	a	110	31	78	75
12.0	b	103	38	73	70
12.0	c	99	48	67	67
12.0	d	99	35	74	67
12.0	e	63	26	71	43
17.2	a	4	144	3	3
17.2	b	3	127	2	2
17.2	c	1	136	1	1
17.2	d	11	127	8	7
17.2	e	3	141	2	2
24.0	a	0	-	0	0
24.0	b	0	-	0	0
24.0	c	0	-	0	0
24.0	d	0	-	0	0
24.0	e	0	-	0.0	0.0

Sampling Event #4: 5/16/2006
Test Initiation Date: 5/17/2006
Species: *Crassostrea gigas*
Sample ID: C

Nominal [Cu] (µg/l)	Rep	Final # Normal	# Abnormal	Percent Normal (%)	Normal Survival (%)
0	a	94	25	79	64
0	b	128	2	98	87
0	c	112	12	90	76
0	d	124	6	95	84
0	e	130	5	96	88
2.9	a	124	5	96	84
2.9	b	111	12	90	76
2.9	c	130	11	92	88
2.9	d	116	9	93	79
2.9	e	121	7	95	82
4.1	a	114	13	90	78
4.1	b	134	12	92	91
4.1	c	134	7	95	91
4.1	d	133	5	96	90
4.1	e	133	4	97	90
5.9	a	70	19	79	48
5.9	b	124	5	96	84
5.9	c	124	5	96	84
5.9	d	125	5	96	85
5.9	e	129	3	98	88
8.4	a	38	7	84	26
8.4	b	68	15	82	46
8.4	c	119	15	89	81
8.4	d	133	12	92	90
8.4	e	136	13	91	93
12.0	a	48	50	49	33
12.0	b	86	35	71	59
12.0	c	86	51	63	59
12.0	d	86	35	71	59
12.0	e	100	46	68	68
17.2	a	0	93	0	0
17.2	b	0	-	0	0
17.2	c	2	87	2	1
17.2	d	4	102	4	3
17.2	e	6	90	6	4
24.0	a	0	-	0	0
24.0	b	0	-	0	0
24.0	c	0	-	0	0
24.0	d	0	-	0	0
24.0	e	0	-	0	0

Sampling Event #4: 5/17/2006
Test Initiation Date: 5/18/2006
Species: *Crassostrea gigas*
Sample ID: WL

Nominal [Cu] (µg/l)	Rep	Final # Normal	# Abnormal	Percent Normal (%)	Normal Survival (%)
0	a	123	14	90	66
0	b	176	6	97	94
0	c	164	5	97	88
0	d	175	8	96	94
0	e	152	15	91	81
2.9	a	115	1	99	61
2.9	b	152	9	94	81
2.9	c	165	15	92	88
2.9	d	147	11	93	79
2.9	e	164	9	95	88
4.1	a	141	6	96	75
4.1	b	176	16	92	94
4.1	c	154	10	94	82
4.1	d	145	14	91	78
4.1	e	142	13	92	76
5.9	a	137	18	88	73
5.9	b	145	9	94	78
5.9	c	140	5	97	75
5.9	d	147	8	95	79
5.9	e	164	10	94	88
8.4	a	100	10	91	53
8.4	b	131	5	96	70
8.4	c	133	18	88	71
8.4	d	185	14	93	99
8.4	e	142	10	93	76
12.0	a	117	10	92	63
12.0	b	159	8	95	85
12.0	c	131	7	95	70
12.0	d	207	16	93	111
12.0	e	156	12	93	83
17.2	a	90	54	63	48
17.2	b	102	47	68	55
17.2	c	109	39	74	58
17.2	d	101	37	73	54
17.2	e	135	4	97	72
24.0	a	25	125	17	13
24.0	b	7	139	5	4
24.0	c	10	120	8	5
24.0	d	24	109	18	13
24.0	e	17	135	11	9
35.0	a	0	-	0	0
35.0	b	0	-	0	0
35.0	c	0	-	0	0
35.0	d	0	-	0	0
35.0	e	0	-	0	0

Sampling Event #4: 5/17/2006
Test Initiation Date: 5/18/2006
Species: *Crassostrea gigas*
Sample ID: ML

Nominal [Cu] (µg/l)	Rep	Final # Normal	# Abnormal	Percent Normal (%)	Normal Survival (%)
0	a	156	9	95	83
0	b	170	14	92	91
0	c	148	12	93	79
0	d	154	12	93	82
0	e	160	11	94	86
2.9	a	161	10	94	86
2.9	b	153	17	90	82
2.9	c	164	14	92	88
2.9	d	157	22	88	84
2.9	e	166	11	94	89
4.1	a	172	14	92	92
4.1	b	165	11	94	88
4.1	c	157	16	91	84
4.1	d	172	13	93	92
4.1	e	168	17	91	90
5.9	a	158	13	92	84
5.9	b	175	12	94	94
5.9	c	157	16	91	84
5.9	d	123	20	86	66
5.9	e	174	19	90	93
8.4	a	164	12	93	88
8.4	b	161	20	89	86
8.4	c	152	24	86	81
8.4	d	165	16	91	88
8.4	e	162	23	88	87
12.0	a	134	22	86	72
12.0	b	129	26	83	69
12.0	c	146	22	87	78
12.0	d	133	27	83	71
12.0	e	136	25	84	73
17.2	a	49	126	28	26
17.2	b	40	131	23	21
17.2	c	61	108	36	33
17.2	d	57	109	34	30
17.2	e	54	129	30	29
24.0	a	0	-	0	0
24.0	b	0	-	0	0
24.0	c	0	-	0	0
24.0	d	0	-	0	0
24.0	e	0	-	0	0

Sampling Event #4: 5/16/2006
Test Initiation Date: 5/17/2006
Species: *Crassostrea gigas*
Sample ID: EL

Nominal [Cu] (µg/l)	Rep	Final # Normal	# Abnormal	Percent Normal (%)	Normal Survival (%)
0	a	147	20	88	100
0	b	139	3	98	95
0	c	103	2	98	70
0	d	116	5	96	79
0	e	126	6	95	86
2.9	a	110	3	97	75
2.9	b	124	4	97	84
2.9	c	106	9	92	72
2.9	d	99	2	98	67
2.9	e	120	6	95	82
4.1	a	122	6	95	83
4.1	b	123	6	95	84
4.1	c	113	9	93	77
4.1	d	73	12	86	50
4.1	e	117	9	93	80
5.9	a	130	18	88	88
5.9	b	140	7	95	95
5.9	c	134	6	96	91
5.9	d	129	13	91	88
5.9	e	117	12	91	80
8.4	a	114	23	83	78
8.4	b	138	22	86	94
8.4	c	97	23	81	66
8.4	d	122	19	87	83
8.4	e	106	24	82	72
12.0	a	69	80	46	47
12.0	b	74	83	47	50
12.0	c	49	56	47	33
12.0	d	65	66	50	44
12.0	e	86	61	59	59
17.2	a	3	142	2	2
17.2	b	2	127	2	1
17.2	c	1	133	1	1
17.2	d	2	136	1	1
17.2	e	6	129	4	4
24.0	a	0	-	0	0
24.0	b	0	-	0	0
24.0	c	0	-	0	0
24.0	d	0	-	0	0
24.0	e	0	-	0	0

Sampling Event #4: 5/17/2006
Test Initiation Date: 5/18/2006
Species: *Crassostrea gigas*
Sample ID: NMC

Nominal [Cu] (µg/l)	Rep	Final # Normal	# Abnormal	Percent Normal (%)	Normal Survival (%)
0	a	173	4	98	93
0	b	154	11	93	82
0	c	121	2	98	65
0	d	143	7	95	76
0	e	164	15	92	88
2.9	a	167	13	93	89
2.9	b	139	10	93	74
2.9	c	146	3	98	78
2.9	d	144	15	91	77
2.9	e	151	16	90	81
4.1	a	176	11	94	94
4.1	b	157	13	92	84
4.1	c	169	12	93	90
4.1	d	162	9	95	87
4.1	e	155	11	93	83
5.9	a	144	11	93	77
5.9	b	167	14	92	89
5.9	c	186	10	95	99
5.9	d	149	18	89	80
5.9	e	178	18	91	95
8.4	a	159	18	90	85
8.4	b	153	13	92	82
8.4	c	171	22	89	91
8.4	d	142	21	87	76
12.0	a	146	49	75	78
12.0	b	132	35	79	71
12.0	c	113	35	76	60
12.0	d	128	46	74	68
12.0	e	97	50	66	52
17.2	a	19	159	11	10
17.2	b	15	149	9	8
17.2	c	19	139	12	10
17.2	d	13	166	7	7
17.2	e	24	152	14	13
24.0	a	0	-	0	0
24.0	b	0	-	0	0
24.0	c	0	-	0	0
24.0	d	0	-	0	0
24.0	e	0	-	0	0

Sampling Event #4: 5/17/2006
Test Initiation Date: 5/18/2006
Species: *Crassostrea gigas*
Sample ID: WLC

Nominal [Cu] (µg/l)	Rep	Final # Normal	# Abnormal	Percent Normal (%)	Normal Survival (%)
0	a	154	9	94	82
0	b	148	5	97	79
0	c	172	1	99	92
0	d	170	4	98	91
0	e	174	7	96	93
2.9	a	155	3	98	83
2.9	b	176	7	96	94
2.9	c	152	10	94	81
2.9	d	145	10	94	78
2.9	e	156	9	95	83
4.1	a	150	4	97	80
4.1	b	147	6	96	79
4.1	c	153	3	98	82
4.1	d	154	5	97	82
4.1	e	185	10	95	99
5.9	a	138	12	92	74
5.9	b	84	4	95	45
5.9	c	161	10	94	86
5.9	d	144	4	97	77
5.9	e	175	9	95	94
8.4	a	180	4	98	96
8.4	b	162	14	92	87
8.4	c	177	11	94	95
8.4	d	130	8	94	70
8.4	e	147	16	90	79
12.0	a	168	15	92	90
12.0	b	143	10	93	76
12.0	c	154	14	92	82
12.0	d	145	10	94	78
12.0	e	164	16	91	88
17.2	a	119	50	70	64
17.2	b	143	50	74	76
17.2	c	137	53	72	73
17.2	d	120	58	67	64
17.2	e	127	44	74	68
24.0	a	19	149	11	10
24.0	b	15	136	10	8
24.0	c	8	158	5	4
24.0	d	16	139	10	9
24.0	e	20	160	11	11
35.0	a	0	-	0	0
35.0	b	0	-	0	0
35.0	c	0	-	0	0
35.0	d	0	-	0	0
35.0	e	0	-	0	0

APPENDIX K

WER: MEASURED COPPER CONCENTRATIONS IN TEST SOLUTIONS

Table K-1. Measured copper concentrations in test solutions from Event 1 for *Mytilus galloprovincialis*.

Site	Copper (µg/L) Nominal	Total Recoverable	Dissolved
SIO1	0	1.4	1.4
	4.1	10.1	4.9
	5.9	12.3	6.1
	8.4	13.4	8.2
	12	15.8	11.8
	17.2	22.5	12.0
GC1	0	0.11	0.11
	4.1	7.6	3.6
	5.9	7.6	4.0
	8.4	11.7	7.8
	12	13.3	8.7
	17.2	19.5	13.6
N	0	0.79	0.85
	4.1	7.3	4.8
	5.9	10.0	6.1
	8.4	10.6	9.0
	12	13.9	9.6
	17.2	22.0	12.0
	24	28.5	19.3
S	0	0.25	0.41
	4.1	6.1	6.4
	5.9	9.7	6.7
	8.4	12.2	7.0
	12	13.3	10.0
	17.2	17.4	13.7
	24	24.6	19.3
C	0	0.65	0.71
	4.1	5.8	5.0
	5.9	7.9	6.0
	8.4	11.1	8.8
	12	13.4	11.0
	17.2	19.1	12.4
	24	34.7	19.7
SIO2	0	1.4	1.4
	4.1	9.6	7.6
	5.9	11.2	6.9
	8.4	13.3	8.6
	12	15.4	11.3
	17.2	20.6	15.9
GC2	0	0.11	0.11
	4.1	5.8	3.6
	5.9	7.2	4.5
	8.4	11.4	7.3
	12	13.0	8.8
	17.2	17.0	13.4
WL	0	0.45	0.34
	4.1	8.9	4.1
	5.9	7.0	4.0
	8.4	10.3	6.7
	12	13.9	7.5
	17.2	17.0	11.5
	24	25.6	14.2
ML	0	0.60	0.59
	4.1	6.5	3.7
	5.9	8.2	4.4
	8.4	11.2	6.7
	12	15.1	7.4
	17.2	17.8	10.5
	24	25.5	16.9
EL	0	0.77	0.61
	4.1	6.7	4.1
	5.9	10.3	3.9
	8.4	11.4	6.6
	12	14.3	7.4
	17.2	20.6	12.4
	24	27.7	16.4
NMC	0	0.69	0.01
	4.1	7.5	3.8
	5.9	8.6	3.9
	8.4	10.8	6.3
	12	14.2	8.3
	17.2	20.2	10.5
	24	26.1	15.4
WLC	0	0.51	0.37
	4.1	5.6	3.7
	5.9	7.1	4.5
	8.4	10.2	7.1
	12	12.6	8.8
	17.2	18.4	11.6
	24	25.5	16.1

Table K-2. Measured copper concentrations in test solutions from Event 2 for *Mytilus galloprovincialis* and *Strongylocentrotus purpuratus*.

Site	Copper (µg/L)		
	Nominal	Total Recoverable	Dissolved
SIO1	0	1.40	1.40
	2.9	5.6	4.3
	4.1	6.8	5.3
	5.9	8.4	5.8
	8.4	13.6	11.1
	12	19.2	13.2
	17.2	21.5	14.8
	24	29.1	24.1
GC1	0	0.11	0.11
	2.9	2.8	4.0
	4.1	5.2	4.2
	5.9	7.1	5.8
	8.4	11.0	7.5
	12	12.0	10.8
	17.2	20.0	16.5
	24	24.7	21.8
N	0	0.72	0.63
	2.9	3.7	4.8
	4.1	5.4	5.0
	5.9	7.2	5.6
	8.4	11.5	7.9
	12	12.3	10.8
	17.2	23.1	14.9
	24	26.3	20.8
	35	33.8	27.0
	50	53.5	40.6
S	0	0.54	0.53
	4.1	5.1	4.4
	5.9	6.7	5.9
	8.4	11.0	6.4
	12	13.2	7.4
	17.2	20.7	12.9
	24	26.2	18.3
	35	34.7	26.3
	50	49.4	35.0
C	0	0.60	0.50
	4.1	6.4	4.7
	5.9	6.9	5.3
	8.4	11.1	7.1
	12	13.6	11.3
	17.2	20.4	13.6
	24	27.4	18.2
	35	33.6	22.8
	50	49.7	37.4

Site	Copper (µg/L)		
	Nominal	Total Recoverable	Dissolved
SIO2	0	1.40	1.40
	2.9	5.6	4.7
	4.1	8.5	5.8
	5.9	8.5	6.1
	8.4	13.1	10.0
	12	14.5	11.5
	17.2	21.7	17.4
	24	29.1	23.7
GC2	0	0.11	0.11
	2.9	3.3	3.5
	4.1	8.8	4.6
	5.9	6.7	4.8
	8.4	10.5	7.5
	12	12.4	10.4
	17.2	19.0	15.7
	24	28.3	21.9
WL	0	0.60	0.44
	4.1	6.4	3.8
	5.9	8.9	3.8
	8.4	10.9	7.5
	12	13.3	8.2
	17.2	21.2	12.3
	24	26.4	16.0
	35	34.1	20.8
	50	49.3	29.9
ML	0	0.68	0.52
	2.9	4.4	3.2
	4.1	6.3	2.5
	5.9	8.0	4.0
	8.4	11.3	7.2
	12	14.3	10.6
	17.2	21.0	13.2
	24	27.1	18.5
	35	36.2	24.1
	50	52.7	37.8
EL	0	0.64	0.50
	2.9	4.6	4.0
	4.1	8.0	5.3
	5.9	9.6	5.6
	8.4	11.6	6.8
	12	14.4	8.8
	17.2	20.6	14.5
	24	26.3	19.1
	35	34.5	26.0
	50	52.2	38.9

Table K-2. Measured copper concentrations in test solutions from Event 2 for *Mytilus galloprovincialis* and *Strongylocentrotus purpuratus*. (cont)

Site	Copper (µg/L)		
	Nominal	Total Recoverable	Dissolved
NMC	0	0.66	0.54
	2.9	3.5	3.4
	4.1	5.4	4.8
	5.9	7.4	4.8
	8.4	11.5	9.4
	12	13.8	10.6
	17.2	21.4	14.6
	24	27.3	19.9
	35	33.1	25.0
	50	49.2	37.4
WLC	0	0.51	0.40
	4.1	5.2	4.0
	5.9	7.1	3.8
	8.4	10.7	9.6
	12	13.3	9.6
	17.2	20.0	12.8
	24	26.8	17.3
	35	33.2	22.6
	50	52.6	33.4

Table K-3. Measured copper concentrations in test solutions from Event 3 for *Mytilus galloprovincialis*.

Site	Copper (µg/L)		
	Nominal	Total Recoverable	Dissolved
SIO	0	1.51	1.51
	2.9	7.1	5.8
	4.1	-	5.2
	5.9	10.0	8.9
	8.4	12.7	9.7
	17.2	22.8	20.0
GC	0	0.06	0.06
	2.9	5.8	3.3
	5.9	9.8	5.7
	8.4	9.6	7.8
	12	13.2	10.0
	17.2	19.6	18.5
N	0	1.69	1.30
	8.4	11.4	8.3
	12	17.2	12.0
	17.2	25.4	13.7
	24	25.7	18.7
	35	39.5	27.8
S	0	1.05	1.02
	8.4	10.7	7.3
	12	17.0	11.6
	17.2	23.1	16.6
	24	25.2	16.9
	35	37.8	26.5
C	0	1.31	1.03
	8.4	10.3	6.9
	12	16.9	9.5
	17.2	23.6	19.3
	24	26.7	22.9
	35	39.7	27.1
WL	0	0.90	0.74
	8.4	9.7	7.0
	12	14.7	9.5
	17.2	24.7	13.6
	24	26.3	14.6
	35	39.0	22.0
EL	0	1.32	1.00
	5.9	9.8	8.0
	8.4	10.4	8.2
	12	17.4	11.2
	17.2	23.6	15.2
	24	24.9	16.7
	35	38.5	27.2

Site	Copper (µg/L)		
	Nominal	Total Recoverable	Dissolved
SIO26	0	1.51	1.51
	2.9	6.3	4.3
	4.1	7.4	4.6
	5.9	10.0	8.3
	8.4	11.1	8.5
	12	16.0	10.1
	17.2	30.8	17.7
ML	0	1.36	0.82
	8.4	10.9	6.0
	12	16.3	11.6
	17.2	23.0	14.8
	24	24.9	16.4
	35	37.8	18.6

Table K-3. Measured copper concentrations in test solutions from Event #3 for *Mytilus galloprovincialis*. (cont)

Site	Copper (µg/L)		
	Nominal	Total Recoverable	Dissolved
NMC	0	1.12	0.91
	8.4	9.8	7.6
	12	12.5	10.6
	17.2	22.1	14.7
	24	31.0	16.3
	35	38.4	27.4
WLC	0	0.87	0.60
	8.4	9.5	6.1
	12	15.7	9.1
	17.2	25.6	11.0
	24	26.7	14.0
	35	39.1	20.8

Table K-4. Measured copper concentrations in test solutions from Event 4 for *Mytilus galloprovincialis* and *Crassostrea gigas*.

Site	Copper (µg/L)	
	Nominal	Total Recoverable
SIO1	0	4.28
	2.9	8.3
	4.1	9.4
	5.9	12.6
	8.4	13.9
	12	21.3
GC1	0	0.12
	2.9	9.3
	4.1	9.3
	5.9	9.9
	8.4	11.6
	12	16.7
N	0	0.76
	4.1	10.7
	5.9	11.2
	8.4	15.3
	12	17.1
	17.2	24.9
S	0	0.53
	5.9	10.4
	8.4	17.4
	12	19.6
	17.2	27.1
	24	35.9
C	0	0.69
	4.1	9.1
	5.9	11.1
	8.4	14.8
	12	17.1
	17.2	25.8
	24	35.1
EL	0	0.70
	5.9	10.8
	8.4	15.4
	12	19.4
	17.2	26.5
	24	37.5

Site	Copper (µg/L)	
	Nominal	Total Recoverable
SIO2	0	4.28
	2.9	-
	4.1	11.6
	5.9	12.5
	8.4	12.6
	12	17.9
	17.2	23.3
GC2	0	0.12
	2.9	3.7
	4.1	7.2
	5.9	7.9
	8.4	10.9
	12	14.9
	17.2	21.7
WL	0	0.67
	5.9	8.4
	8.4	11.8
	12	16.1
	17.2	21.3
	24	29.0
	35	41.2
ML	0	0.71
	5.9	9.8
	8.4	10.4
	12	15.8
	17.2	23.3
	24	34.4
NMC	0	0.76
	5.9	9.1
	8.4	11.63
	12	15.7
	17.2	22.1
	24	32.6
WLC	0	0.68
	8.4	12.6
	12	17.2
	17.2	22.7
	24	32.5
	35	42.1

APPENDIX L

CORMIX SESSION REPORT

CORMIX MIXING ZONE EXPERT SYSTEM

CORMIX-GI Version 4.3GT

HYDRO3:Version-4.3.0.2 June,2005

SITE NAME/LABEL: Pearl Harbor Naval Shipyard & IMF Effluent Study

DESIGN CASE: 0 foot discharge at maximum concentration of 50 µg/L

****

SUMMARY OF INPUT DATA:

AMBIENT PARAMETERS:

Cross-section = bounded

Width BS = 600 m

Channel regularity ICHREG = 1

Ambient flowrate QA = 182.88 m^3/s

Average depth HA = 15.24 m

Depth at discharge HD = 15.24 m

Ambient velocity UA = 0.02 m/s

Darcy-Weisbach friction factor F = 0.0071

Calculated from Manning's n = 0.015

Wind velocity UW = 0 m/s

Stratification Type STRCND = U

Surface density RHOAS = 1023 kg/m^3

Bottom density RHOAB = 1023 kg/m^3

DISCHARGE PARAMETERS: Buoyant Surface Discharge

Discharge located on = left bank/shoreline

Discharge configuration = flush discharge

Distance from bank to outlet DISTB = 0 m

Discharge angle SIGMA = 90 deg

Depth near discharge outlet HD0 = 15.24 m

Bottom slope at discharge SLOPE = 0 deg

Circular pipe diameter = 0.2565 m

Equivalent rectangular discharge:

Discharge cross-section area A0 = 0.051681 m^2

Discharge channel width   B0   = 0.201470 m
Discharge channel depth   H0   = 0.25652 m
Discharge aspect ratio   AR   = 1.273240
Discharge flowrate   Q0   = 0.189271 m^3/s
Discharge velocity   U0   = 3.66 m/s
Discharge density   RHO0 = 1017 kg/m^3
Density difference   DRHO = 6 kg/m^3
Buoyant acceleration   GP0 = 0.0575 m/s^2
Discharge concentration   C0   = 50 µg/L
Surface heat exchange coeff. KS   = 0 m/s
Coefficient of decay   KD   = 0 /s

DISCHARGE/ENVIRONMENT LENGTH SCALES:
LQ = 0.23 m   Lm = 41.63 m   Lbb = 1360.79 m
LM = 7.28 m

NON-DIMENSIONAL PARAMETERS:
Densimetric Froude number   FR0 = 32.03 (based on LQ)
Channel densimetric Froude no. FRCH = 30.15 (based on H0)
Velocity ratio   R   = 183.11

MIXING ZONE / TOXIC DILUTION ZONE / AREA OF INTEREST PARAMETERS:
Toxic discharge   = no
Water quality standard specified   = yes
Water quality standard   CSTD = 17.600000 µg/L
Regulatory mixing zone   = yes
Regulatory mixing zone specification = distance
Regulatory mixing zone value   = 4.57 m (m^2 if area)
Region of interest   = 6000 m
****
HYDRODYNAMIC CLASSIFICATION:

| FLOW CLASS = FJ1 |

****

MIXING ZONE EVALUATION (hydrodynamic and regulatory summary):

X-Y-Z Coordinate system:

Origin is located at water surface and at centerline of discharge channel:

0 m from the left bank/shore.

Number of display steps NSTEP = 100 per module.

NEAR-FIELD REGION (NFR) CONDITIONS :

Note: The NFR is the zone of strong initial mixing. It has no regulatory implication. However, this information may be useful for the discharge designer because the mixing in the NFR is usually sensitive to the discharge design conditions.

Pollutant concentration at edge of NFR = 0.5136 µg/L

Dilution at edge of NFR = 97.3

NFR Location: x = 177.64 m

(centerline coordinates) y = -600 m

z = 0 m

NFR plume dimensions: half-width = 461.65 m

thickness = 1.43 m

Cumulative travel time: 8391.5684 sec.

Buoyancy assessment:

The effluent density is less than the surrounding ambient water density at the discharge level.

Therefore, the effluent is POSITIVELY BUOYANT and will tend to rise towards the surface.

FAR-FIELD MIXING SUMMARY:

Plume becomes laterally fully mixed at 183.37 m downstream.

PLUME BANK CONTACT SUMMARY:

Plume in bounded section contacts nearest bank at 177.64 m downstream.

Plume contacts second bank at 183.37 m downstream.

*********************** TOXIC DILUTION ZONE SUMMARY ************************

No TDZ was specified for this simulation.

********************* REGULATORY MIXING ZONE SUMMARY **********************

The plume conditions at the boundary of the specified RMZ are as follows:

Pollutant concentration = 1.926546 µg/L

Corresponding dilution = 26.0

Plume location: x = 4.57 m

(centerline coordinates) y = -45.58 m

z = 0 m

Plume dimensions: half-width = 13.82 m

thickness = 1.64 m

Cumulative travel time < 8391.5684 sec. (RMZ is within NFR)

At this position, the plume is CONTACTING the LEFT bank.

Furthermore, the specified water quality standard has indeed been met

within the RMZ. In particular:

The ambient water quality standard was encountered at the following

plume position:

Water quality standard = 17.600000 µg/L

Corresponding dilution = 2.8

Plume location: x = 0.06 m

(centerline coordinates) y = -4.27 m

z = 0 m

Plume dimensions: half-width = 0.66 m

thickness = 0.56 m

********************* FINAL DESIGN ADVICE AND COMMENTS **********************

REMINDER: The user must take note that HYDRODYNAMIC MODELING by any known technique is NOT AN EXACT SCIENCE.

Extensive comparison with field and laboratory data has shown that the

CORMIX predictions on dilutions and concentrations (with associated

plume geometries) are reliable for the majority of cases and are accurate

to within about +-50% (standard deviation).

As a further safeguard, CORMIX will not give predictions whenever it judges the design configuration as highly complex and uncertain for prediction.

APPENDIX M

CORMIX PREDICTION FILE

CORMIX MIXING ZONE EXPERT SYSTEM
Subsystem CORMIX3: Buoyant Surface Discharges
CORMIX-GI Version 4.3GT
HYDRO3 Version 4.3.0.2 June 2005

CASE DESCRIPTION
Site name/label: Pearl Harbor Naval Shipyard & IMF Effluent Study
Design case: 0 foot discharge at maximum concentration of 50 µg/L

ENVIRONMENT PARAMETERS (metric units)
Bounded section
BS = 600.00 AS = 9144.00 QA = 182.88 ICHREG= 1
HA = 15.24 HD = 15.24
UA = 0.020 F = 0.007 USTAR =0.5969E-03
UW = 0.000 UWSTAR=0.0000E+00
Uniform density environment
STRCND= U RHOAM = 1023.0000

DISCHARGE PARAMETERS (metric units)
BANK = LEFT DISTB = 0.00 Configuration: flush_discharge
SIGMA = 90.00 HD0 = 15.24 SLOPE = 0.00
Circular discharge pipe:
D0 = 0.257 A0 = 0.052
Dimensions of equivalent rectangular discharge:
B0 = 0.201 H0 = 0.257 A0 =0.5168E-01 AR = 1.273
U0 = 3.662 Q0 = 0.189 =0.1893E+00
RHO0 = 1017.0000 DRHO0 =0.6000E+01 GP0 =0.5752E-01
C0 =0.5000E+02 CUNITS= µg/L
IPOLL = 1 KS =0.0000E+00 KD =0.0000E+00

FLUX VARIABLES (metric units)
Q0 =0.1893E+00 M0 =0.6932E+00 J0 =0.1089E-01
Associated length scales (meters)
LQ = 0.23 LM = 7.28 Lm = 41.63 Lb = 1360.79

NON-DIMENSIONAL PARAMETERS
FR0 = 32.03 FRCH = 30.15 R = 183.11

FLOW CLASSIFICATION
333333333333333333333333333333333333333333
3 Flow class (CORMIX3) = FJ1 3
3 Applicable layer depth HS = 15.24 3
333333333333333333333333333333333333333333

MIXING ZONE / TOXIC DILUTION / REGION OF INTEREST PARAMETERS
C0 =0.5000E+02 CUNITS= µg/L
NTOX = 0
NSTD = 1 CSTD =0.1760E+02
REGMZ = 1

```
 REGSPC= 1     XREG =   4.57 WREG =   0.00 AREG =   0.00
 XINT =  6000.00 XMAX =  6000.00

X-Y-Z COORDINATE SYSTEM:
  ORIGIN is located at the WATER SURFACE and at center of discharge
   channel/outlet:   0.00 m from the LEFT bank/shore.
  X-axis points downstream
  Y-axis points to left as seen by an observer looking downstream
  Z-axis points vertically upward (in CORMIX3, all values Z = 0.00)
NSTEP = 100 display intervals per module
-----------------------------------------------------------------------------
-----------------------------------------------------------------------------
BEGIN MOD301: DISCHARGE MODULE

 Efflux conditions:
    X    Y    Z    S    C    BV    BH
   0.00   0.00  0.00   1.0 0.500E+02  0.26   0.10

END OF MOD301: DISCHARGE MODULE
-----------------------------------------------------------------------------
-----------------------------------------------------------------------------
BEGIN MOD302: ZONE OF FLOW ESTABLISHMENT

 Control volume inflow:
    X    Y    Z    S    C    BV    BH
   0.00   0.00  0.00   1.0 0.500E+02  0.26   0.10

 Profile definitions:
  BV = Gaussian 1/e (37%) vertical thickness
  BH = Gaussian 1/e (37%) horizontal half-width, normal to trajectory
  S = hydrodynamic centerline dilution
  C = centerline concentration (includes reaction effects, if any)

 Control volume outflow:                SIGMAE=  270.03
    X    Y    Z    S    C    BV    BH
   0.00  -1.09  0.00   1.0 0.500E+02  0.26   0.18
 Cumulative travel time =       0.2971 sec

END OF MOD302: ZONE OF FLOW ESTABLISHMENT
-----------------------------------------------------------------------------
-----------------------------------------------------------------------------
BEGIN CORSURF (MOD310): BUOYANT SURFACE JET - NEAR-FIELD REGION

 Surface jet in deep crossflow with strong buoyancy effects.

 Profile definitions:
  BV = Gaussian 1/e (37%) vertical thickness
  BH = Gaussian 1/e (37%) horizontal half-width, normal to trajectory
  S = hydrodynamic centerline dilution
  C = centerline concentration (includes reaction effects, if any)
```

```
   X    Y    Z    S    C    BV    BH
  0.00  -1.09  0.00   1.0 0.500E+02  0.26   0.18
** WATER QUALITY STANDARD OR CCC HAS BEEN FOUND **
 The pollutant concentration in the plume falls below water quality standard
  or CCC value of 0.176E+02 in the current prediction interval.
 This is the spatial extent of concentrations exceeding the water quality
  standard or CCC value.
  0.09  -5.58  0.00   3.5 0.141E+02  0.66   0.88
  0.22  -9.67  0.00   5.9 0.846E+01  0.94   1.64
  0.44  -13.76  0.00   8.5 0.585E+01  1.20   2.56
  0.77  -18.05  0.00  11.5 0.435E+01  1.42   3.68
  1.15  -22.13  0.00  14.2 0.353E+01  1.55   4.90
  1.61  -26.20  0.00  16.6 0.301E+01  1.61   6.25
  2.12  -30.26  0.00  18.9 0.265E+01  1.64   7.69
  2.73  -34.53  0.00  21.0 0.238E+01  1.65   9.30
  3.36  -38.57  0.00  22.9 0.218E+01  1.65  10.90
  4.04  -42.61  0.00  24.7 0.202E+01  1.64  12.56
 ** REGULATORY MIXING ZONE BOUNDARY is within the Near-Field Region (NFR) **
 In this prediction interval the plume distance meets or exceeds
  the regulatory value =   4.57 m.
 This is the extent of the REGULATORY MIXING ZONE.
  4.81  -46.85  0.00  26.5 0.189E+01  1.64  14.37
  5.59  -50.87  0.00  28.1 0.178E+01  1.63  16.13
  6.41  -54.88  0.00  29.6 0.169E+01  1.62  17.94
  7.27  -58.88  0.00  31.1 0.161E+01  1.61  19.79
  8.22  -63.08  0.00  32.6 0.153E+01  1.60  21.77
  9.17  -67.07  0.00  34.0 0.147E+01  1.59  23.70
  10.16  -71.04  0.00  35.4 0.141E+01  1.58  25.65
  11.24  -75.21  0.00  36.7 0.136E+01  1.58  27.74
  12.30  -79.17  0.00  38.0 0.132E+01  1.57  29.76
  13.40  -83.11  0.00  39.2 0.127E+01  1.56  31.80
  14.53  -87.04  0.00  40.4 0.124E+01  1.55  33.87
  15.76  -91.17  0.00  41.7 0.120E+01  1.55  36.07
  16.96  -95.09  0.00  42.8 0.117E+01  1.54  38.19
  18.19  -98.99  0.00  43.9 0.114E+01  1.53  40.33
  19.46 -102.89  0.00  45.0 0.111E+01  1.53  42.50
  20.82 -106.97  0.00  46.2 0.108E+01  1.52  44.80
  22.15 -110.85  0.00  47.2 0.106E+01  1.52  47.00
  23.51 -114.71  0.00  48.2 0.104E+01  1.51  49.22
  24.97 -118.76  0.00  49.3 0.101E+01  1.51  51.58
  26.39 -122.60  0.00  50.3 0.994E+00  1.50  53.84
  27.84 -126.43  0.00  51.3 0.975E+00  1.50  56.11
  29.31 -130.25  0.00  52.2 0.957E+00  1.49  58.40
  30.89 -134.26  0.00  53.2 0.939E+00  1.49  60.83
  32.42 -138.06  0.00  54.1 0.923E+00  1.48  63.15
  33.97 -141.85  0.00  55.1 0.908E+00  1.48  65.48
  35.64 -145.82  0.00  56.0 0.893E+00  1.47  67.95
  37.24 -149.59  0.00  56.9 0.879E+00  1.47  70.31
  38.87 -153.34  0.00  57.8 0.866E+00  1.46  72.68
  40.53 -157.09  0.00  58.6 0.853E+00  1.46  75.07
  42.30 -161.02  0.00  59.5 0.840E+00  1.45  77.59
```

44.00	-164.74	0.00	60.3	0.829E+00	1.45	80.00
45.73	-168.45	0.00	61.2	0.817E+00	1.45	82.41
47.57	-172.35	0.00	62.0	0.806E+00	1.44	84.97
49.34	-176.04	0.00	62.8	0.796E+00	1.44	87.40
51.14	-179.72	0.00	63.6	0.786E+00	1.43	89.84
52.96	-183.39	0.00	64.4	0.777E+00	1.43	92.30
54.89	-187.24	0.00	65.2	0.767E+00	1.43	94.89
56.75	-190.88	0.00	66.0	0.758E+00	1.42	97.36
58.63	-194.52	0.00	66.7	0.749E+00	1.42	99.83
60.53	-198.15	0.00	67.5	0.741E+00	1.41	102.31
62.55	-201.95	0.00	68.2	0.733E+00	1.41	104.93
64.49	-205.56	0.00	69.0	0.725E+00	1.41	107.43
66.45	-209.15	0.00	69.7	0.718E+00	1.40	109.93
68.53	-212.93	0.00	70.4	0.710E+00	1.40	112.57
70.53	-216.50	0.00	71.1	0.703E+00	1.39	115.08
72.55	-220.06	0.00	71.8	0.696E+00	1.39	117.59
74.58	-223.61	0.00	72.5	0.690E+00	1.39	120.11
76.74	-227.34	0.00	73.2	0.683E+00	1.38	122.77
78.81	-230.87	0.00	73.9	0.677E+00	1.38	125.30
80.90	-234.40	0.00	74.6	0.670E+00	1.38	127.83
83.12	-238.09	0.00	75.3	0.664E+00	1.37	130.50
85.24	-241.59	0.00	75.9	0.659E+00	1.37	133.03
87.38	-245.08	0.00	76.6	0.653E+00	1.36	135.57
89.53	-248.56	0.00	77.2	0.648E+00	1.36	138.12
91.82	-252.22	0.00	77.9	0.642E+00	1.36	140.79
94.01	-255.68	0.00	78.5	0.637E+00	1.35	143.34
96.21	-259.13	0.00	79.1	0.632E+00	1.35	145.89
98.55	-262.75	0.00	79.8	0.627E+00	1.34	148.57
100.78	-266.18	0.00	80.4	0.622E+00	1.34	151.12
103.03	-269.60	0.00	81.0	0.617E+00	1.34	153.67
105.30	-273.01	0.00	81.6	0.613E+00	1.33	156.23
107.69	-276.59	0.00	82.2	0.608E+00	1.33	158.91
109.99	-279.98	0.00	82.8	0.604E+00	1.33	161.46
112.30	-283.37	0.00	83.4	0.599E+00	1.32	164.02
114.62	-286.74	0.00	84.0	0.595E+00	1.32	166.57
117.08	-290.28	0.00	84.6	0.591E+00	1.32	169.26
119.42	-293.63	0.00	85.2	0.587E+00	1.31	171.81
121.79	-296.97	0.00	85.8	0.583E+00	1.31	174.36
124.29	-300.48	0.00	86.4	0.579E+00	1.30	177.04
126.68	-303.81	0.00	86.9	0.575E+00	1.30	179.59
129.08	-307.12	0.00	87.5	0.572E+00	1.30	182.14
131.50	-310.43	0.00	88.0	0.568E+00	1.29	184.69
134.05	-313.90	0.00	88.6	0.564E+00	1.29	187.37
136.49	-317.18	0.00	89.1	0.561E+00	1.29	189.91
138.94	-320.46	0.00	89.7	0.558E+00	1.28	192.45
141.54	-323.90	0.00	90.2	0.554E+00	1.28	195.12
144.02	-327.16	0.00	90.8	0.551E+00	1.28	197.66
146.50	-330.41	0.00	91.3	0.548E+00	1.27	200.20
149.00	-333.66	0.00	91.8	0.544E+00	1.27	202.73
151.65	-337.06	0.00	92.4	0.541E+00	1.27	205.40
154.17	-340.28	0.00	92.9	0.538E+00	1.26	207.93

156.70 -343.50 0.00 93.4 0.535E+00 1.26 210.45
159.38 -346.87 0.00 94.0 0.532E+00 1.26 213.11
161.94 -350.07 0.00 94.5 0.529E+00 1.25 215.63
164.51 -353.26 0.00 95.0 0.527E+00 1.25 218.15
167.08 -356.44 0.00 95.5 0.524E+00 1.25 220.66
169.81 -359.78 0.00 96.0 0.521E+00 1.24 223.31
172.41 -362.94 0.00 96.5 0.518E+00 1.24 225.82
175.02 -366.10 0.00 97.0 0.516E+00 1.24 228.32
177.64 -369.25 0.00 97.4 0.513E+00 1.23 230.83
Jet/plume APPROACHES OPPOSITE BANK at above position.
Flow continues as WALL JET/PLUME.
177.64 -600.00 0.00 97.3 0.514E+00 1.43 461.65
Buoyant jet regime ends with local CRITICAL CONDITIONS.
Cumulative travel time = 8391.5684 sec

END OF CORSURF (MOD310): BUOYANT SURFACE JET - NEAR-FIELD REGION

Bank nearest to plume centerline has changed.
Nearest bank is now on RIGHT.

** End of NEAR-FIELD REGION (NFR***) **

The initial plume WIDTH/THICKNESS VALUE in the next far-field module will be CORRECTED by a factor 1.18 to conserve the mass flux in the far-field!

Some bank/shore interaction occurs at end of near-field.

In the next prediction module, the jet/plume centerline will be set to follow the bank/shore.

BEGIN MOD341: BUOYANT AMBIENT SPREADING

Plume is ATTACHED to RIGHT bank/shore.
Plume width is now determined from RIGHT bank/shore.

Profile definitions:
BV = top-hat thickness,measured vertically
BH = top-hat half-width, measured horizontally from bank/shoreline
S = hydrodynamic average (bulk) dilution
C = average (bulk) concentration (includes reaction effects, if any)

Plume Stage 2 (bank attached):
X Y Z S C BV BH
177.64 -600.00 0.00 97.3 0.514E+00 1.69 544.80
177.69 -600.00 0.00 97.4 0.513E+00 1.69 545.37
177.75 -600.00 0.00 97.4 0.513E+00 1.69 545.94
177.81 -600.00 0.00 97.4 0.513E+00 1.69 546.51
177.86 -600.00 0.00 97.5 0.513E+00 1.68 547.09
177.92 -600.00 0.00 97.5 0.513E+00 1.68 547.66
177.98 -600.00 0.00 97.5 0.513E+00 1.68 548.23

178.04	-600.00	0.00	97.5	0.513E+00	1.68	548.80
178.09	-600.00	0.00	97.6	0.513E+00	1.68	549.37
178.15	-600.00	0.00	97.6	0.512E+00	1.68	549.93
178.21	-600.00	0.00	97.6	0.512E+00	1.68	550.50
178.27	-600.00	0.00	97.6	0.512E+00	1.68	551.07
178.32	-600.00	0.00	97.7	0.512E+00	1.67	551.64
178.38	-600.00	0.00	97.7	0.512E+00	1.67	552.21
178.44	-600.00	0.00	97.7	0.512E+00	1.67	552.77
178.50	-600.00	0.00	97.7	0.512E+00	1.67	553.34
178.55	-600.00	0.00	97.8	0.511E+00	1.67	553.91
178.61	-600.00	0.00	97.8	0.511E+00	1.67	554.47
178.67	-600.00	0.00	97.8	0.511E+00	1.67	555.04
178.72	-600.00	0.00	97.9	0.511E+00	1.66	555.61
178.78	-600.00	0.00	97.9	0.511E+00	1.66	556.17
178.84	-600.00	0.00	97.9	0.511E+00	1.66	556.73
178.90	-600.00	0.00	97.9	0.511E+00	1.66	557.30
178.95	-600.00	0.00	98.0	0.510E+00	1.66	557.86
179.01	-600.00	0.00	98.0	0.510E+00	1.66	558.43
179.07	-600.00	0.00	98.0	0.510E+00	1.66	558.99
179.13	-600.00	0.00	98.0	0.510E+00	1.66	559.55
179.18	-600.00	0.00	98.1	0.510E+00	1.66	560.11
179.24	-600.00	0.00	98.1	0.510E+00	1.65	560.68
179.30	-600.00	0.00	98.1	0.510E+00	1.65	561.24
179.35	-600.00	0.00	98.1	0.509E+00	1.65	561.80
179.41	-600.00	0.00	98.2	0.509E+00	1.65	562.36
179.47	-600.00	0.00	98.2	0.509E+00	1.65	562.92
179.53	-600.00	0.00	98.2	0.509E+00	1.65	563.48
179.58	-600.00	0.00	98.2	0.509E+00	1.65	564.04
179.64	-600.00	0.00	98.3	0.509E+00	1.65	564.60
179.70	-600.00	0.00	98.3	0.509E+00	1.64	565.16
179.76	-600.00	0.00	98.3	0.509E+00	1.64	565.72
179.81	-600.00	0.00	98.3	0.508E+00	1.64	566.27
179.87	-600.00	0.00	98.4	0.508E+00	1.64	566.83
179.93	-600.00	0.00	98.4	0.508E+00	1.64	567.39
179.99	-600.00	0.00	98.4	0.508E+00	1.64	567.95
180.04	-600.00	0.00	98.4	0.508E+00	1.64	568.50
180.10	-600.00	0.00	98.5	0.508E+00	1.64	569.06
180.16	-600.00	0.00	98.5	0.508E+00	1.63	569.62
180.21	-600.00	0.00	98.5	0.507E+00	1.63	570.17
180.27	-600.00	0.00	98.5	0.507E+00	1.63	570.73
180.33	-600.00	0.00	98.6	0.507E+00	1.63	571.28
180.39	-600.00	0.00	98.6	0.507E+00	1.63	571.84
180.44	-600.00	0.00	98.6	0.507E+00	1.63	572.39
180.50	-600.00	0.00	98.6	0.507E+00	1.63	572.95
180.56	-600.00	0.00	98.7	0.507E+00	1.63	573.50
180.62	-600.00	0.00	98.7	0.507E+00	1.63	574.05
180.67	-600.00	0.00	98.7	0.506E+00	1.62	574.60
180.73	-600.00	0.00	98.8	0.506E+00	1.62	575.16
180.79	-600.00	0.00	98.8	0.506E+00	1.62	575.71
180.84	-600.00	0.00	98.8	0.506E+00	1.62	576.26
180.90	-600.00	0.00	98.8	0.506E+00	1.62	576.81

180.96	-600.00	0.00	98.9	0.506E+00	1.62	577.36
181.02	-600.00	0.00	98.9	0.506E+00	1.62	577.91
181.07	-600.00	0.00	98.9	0.506E+00	1.62	578.46
181.13	-600.00	0.00	98.9	0.505E+00	1.62	579.01
181.19	-600.00	0.00	98.9	0.505E+00	1.61	579.56
181.25	-600.00	0.00	99.0	0.505E+00	1.61	580.11
181.30	-600.00	0.00	99.0	0.505E+00	1.61	580.66
181.36	-600.00	0.00	99.0	0.505E+00	1.61	581.21
181.42	-600.00	0.00	99.0	0.505E+00	1.61	581.76
181.48	-600.00	0.00	99.1	0.505E+00	1.61	582.31
181.53	-600.00	0.00	99.1	0.505E+00	1.61	582.86
181.59	-600.00	0.00	99.1	0.504E+00	1.61	583.40
181.65	-600.00	0.00	99.1	0.504E+00	1.61	583.95
181.70	-600.00	0.00	99.2	0.504E+00	1.60	584.50
181.76	-600.00	0.00	99.2	0.504E+00	1.60	585.04
181.82	-600.00	0.00	99.2	0.504E+00	1.60	585.59
181.88	-600.00	0.00	99.2	0.504E+00	1.60	586.13
181.93	-600.00	0.00	99.3	0.504E+00	1.60	586.68
181.99	-600.00	0.00	99.3	0.504E+00	1.60	587.22
182.05	-600.00	0.00	99.3	0.503E+00	1.60	587.77
182.11	-600.00	0.00	99.3	0.503E+00	1.60	588.31
182.16	-600.00	0.00	99.4	0.503E+00	1.60	588.86
182.22	-600.00	0.00	99.4	0.503E+00	1.59	589.40
182.28	-600.00	0.00	99.4	0.503E+00	1.59	589.94
182.33	-600.00	0.00	99.4	0.503E+00	1.59	590.49
182.39	-600.00	0.00	99.5	0.503E+00	1.59	591.03
182.45	-600.00	0.00	99.5	0.503E+00	1.59	591.57
182.51	-600.00	0.00	99.5	0.502E+00	1.59	592.11
182.56	-600.00	0.00	99.5	0.502E+00	1.59	592.65
182.62	-600.00	0.00	99.6	0.502E+00	1.59	593.20
182.68	-600.00	0.00	99.6	0.502E+00	1.59	593.74
182.74	-600.00	0.00	99.6	0.502E+00	1.58	594.28
182.79	-600.00	0.00	99.6	0.502E+00	1.58	594.82
182.85	-600.00	0.00	99.7	0.502E+00	1.58	595.36
182.91	-600.00	0.00	99.7	0.502E+00	1.58	595.90
182.97	-600.00	0.00	99.7	0.501E+00	1.58	596.44
183.02	-600.00	0.00	99.7	0.501E+00	1.58	596.97
183.08	-600.00	0.00	99.8	0.501E+00	1.58	597.51
183.14	-600.00	0.00	99.8	0.501E+00	1.58	598.05
183.19	-600.00	0.00	99.8	0.501E+00	1.58	598.59
183.25	-600.00	0.00	99.8	0.501E+00	1.58	599.13
183.31	-600.00	0.00	99.8	0.501E+00	1.57	599.66
183.37	-600.00	0.00	99.9	0.501E+00	1.57	600.00

Cumulative travel time = 8677.8428 sec

Plume is LATERALLY FULLY MIXED at the end of the buoyant spreading regime.

END OF MOD341: BUOYANT AMBIENT SPREADING

BEGIN MOD361: PASSIVE AMBIENT MIXING IN UNIFORM AMBIENT

Vertical diffusivity (initial value) = 0.182E-02 m^2/s
Horizontal diffusivity (initial value) = 0.228E-02 m^2/s

Profile definitions:
BV = Gaussian s.d.*sqrt(pi/2) (46%) thickness, measured vertically
= or equal to water depth, if fully mixed
BH = Gaussian s.d.*sqrt(pi/2) (46%) half-width,
measured horizontally in Y-direction
S = hydrodynamic centerline dilution
C = centerline concentration (includes reaction effects, if any)

Plume Stage 2 (bank attached):

X	Y	Z	S	C	BV	BH
183.37	-600.00	0.00	99.9	0.501E+00	1.57	600.00
241.53	-600.00	0.00	99.9	0.501E+00	1.57	600.00
299.70	-600.00	0.00	99.9	0.501E+00	1.57	600.00
357.87	-600.00	0.00	99.9	0.501E+00	1.57	600.00
416.03	-600.00	0.00	99.9	0.501E+00	1.57	600.00
474.20	-600.00	0.00	99.9	0.501E+00	1.57	600.00
532.36	-600.00	0.00	99.9	0.501E+00	1.57	600.00
590.53	-600.00	0.00	99.9	0.501E+00	1.57	600.00
648.70	-600.00	0.00	99.9	0.501E+00	1.57	600.00
706.86	-600.00	0.00	99.9	0.501E+00	1.57	600.00
765.03	-600.00	0.00	99.9	0.501E+00	1.57	600.00
823.20	-600.00	0.00	99.9	0.501E+00	1.57	600.00
881.36	-600.00	0.00	99.9	0.501E+00	1.57	600.00
939.53	-600.00	0.00	99.9	0.501E+00	1.57	600.00
997.70	-600.00	0.00	99.9	0.501E+00	1.57	600.00
1055.86	-600.00	0.00	99.9	0.501E+00	1.57	600.00
1114.03	-600.00	0.00	99.9	0.501E+00	1.57	600.00
1172.19	-600.00	0.00	99.9	0.501E+00	1.57	600.00
1230.36	-600.00	0.00	99.9	0.501E+00	1.57	600.00
1288.53	-600.00	0.00	99.9	0.501E+00	1.57	600.00
1346.69	-600.00	0.00	99.9	0.501E+00	1.57	600.00
1404.86	-600.00	0.00	99.9	0.501E+00	1.57	600.00
1463.03	-600.00	0.00	99.9	0.501E+00	1.57	600.00
1521.19	-600.00	0.00	99.9	0.501E+00	1.57	600.00
1579.36	-600.00	0.00	99.9	0.501E+00	1.57	600.00
1637.53	-600.00	0.00	99.9	0.501E+00	1.57	600.00
1695.69	-600.00	0.00	99.9	0.501E+00	1.57	600.00
1753.86	-600.00	0.00	99.9	0.501E+00	1.57	600.00
1812.02	-600.00	0.00	99.9	0.501E+00	1.57	600.00
1870.19	-600.00	0.00	99.9	0.501E+00	1.57	600.00
1928.36	-600.00	0.00	99.9	0.501E+00	1.57	600.00
1986.52	-600.00	0.00	99.9	0.501E+00	1.57	600.00
2044.69	-600.00	0.00	99.9	0.501E+00	1.57	600.00
2102.86	-600.00	0.00	99.9	0.501E+00	1.57	600.00
2161.02	-600.00	0.00	99.9	0.501E+00	1.57	600.00
2219.19	-600.00	0.00	99.9	0.501E+00	1.57	600.00
2277.35	-600.00	0.00	99.9	0.501E+00	1.57	600.00
2335.52	-600.00	0.00	99.9	0.501E+00	1.57	600.00

2393.69	-600.00	0.00	99.9	0.501E+00	1.57	600.00
2451.85	-600.00	0.00	99.9	0.501E+00	1.57	600.00
2510.02	-600.00	0.00	99.9	0.501E+00	1.57	600.00
2568.19	-600.00	0.00	99.9	0.501E+00	1.57	600.00
2626.35	-600.00	0.00	99.9	0.501E+00	1.57	600.00
2684.52	-600.00	0.00	99.9	0.501E+00	1.57	600.00
2742.69	-600.00	0.00	99.9	0.501E+00	1.57	600.00
2800.85	-600.00	0.00	99.9	0.501E+00	1.57	600.00
2859.02	-600.00	0.00	99.9	0.501E+00	1.57	600.00
2917.18	-600.00	0.00	99.9	0.501E+00	1.57	600.00
2975.35	-600.00	0.00	99.9	0.501E+00	1.57	600.00
3033.52	-600.00	0.00	99.9	0.501E+00	1.57	600.00
3091.68	-600.00	0.00	99.9	0.501E+00	1.57	600.00
3149.85	-600.00	0.00	99.9	0.501E+00	1.57	600.00
3208.02	-600.00	0.00	99.9	0.501E+00	1.57	600.00
3266.18	-600.00	0.00	99.9	0.501E+00	1.57	600.00
3324.35	-600.00	0.00	99.9	0.501E+00	1.57	600.00
3382.51	-600.00	0.00	99.9	0.501E+00	1.57	600.00
3440.68	-600.00	0.00	99.9	0.501E+00	1.57	600.00
3498.85	-600.00	0.00	99.9	0.501E+00	1.57	600.00
3557.01	-600.00	0.00	99.9	0.501E+00	1.57	600.00
3615.18	-600.00	0.00	99.9	0.501E+00	1.57	600.00
3673.35	-600.00	0.00	99.9	0.501E+00	1.57	600.00
3731.51	-600.00	0.00	99.9	0.501E+00	1.57	600.00
3789.68	-600.00	0.00	99.9	0.501E+00	1.57	600.00
3847.84	-600.00	0.00	99.9	0.501E+00	1.57	600.00
3906.01	-600.00	0.00	99.9	0.501E+00	1.57	600.00
3964.18	-600.00	0.00	99.9	0.501E+00	1.57	600.00
4022.34	-600.00	0.00	99.9	0.501E+00	1.57	600.00
4080.51	-600.00	0.00	99.9	0.501E+00	1.57	600.00
4138.68	-600.00	0.00	99.9	0.501E+00	1.57	600.00
4196.84	-600.00	0.00	99.9	0.501E+00	1.57	600.00
4255.01	-600.00	0.00	99.9	0.501E+00	1.57	600.00
4313.17	-600.00	0.00	99.9	0.501E+00	1.57	600.00
4371.34	-600.00	0.00	99.9	0.501E+00	1.57	600.00
4429.51	-600.00	0.00	99.9	0.501E+00	1.57	600.00
4487.67	-600.00	0.00	99.9	0.501E+00	1.57	600.00
4545.84	-600.00	0.00	99.9	0.501E+00	1.57	600.00
4604.01	-600.00	0.00	99.9	0.501E+00	1.57	600.00
4662.17	-600.00	0.00	99.9	0.501E+00	1.57	600.00
4720.34	-600.00	0.00	99.9	0.501E+00	1.57	600.00
4778.51	-600.00	0.00	99.9	0.501E+00	1.57	600.00
4836.67	-600.00	0.00	99.9	0.501E+00	1.57	600.00
4894.84	-600.00	0.00	99.9	0.501E+00	1.57	600.00
4953.01	-600.00	0.00	99.9	0.501E+00	1.57	600.00
5011.17	-600.00	0.00	99.9	0.501E+00	1.57	600.00
5069.34	-600.00	0.00	99.9	0.501E+00	1.57	600.00
5127.51	-600.00	0.00	99.9	0.501E+00	1.57	600.00
5185.67	-600.00	0.00	99.9	0.501E+00	1.57	600.00
5243.84	-600.00	0.00	99.9	0.501E+00	1.57	600.00
5302.01	-600.00	0.00	99.9	0.501E+00	1.57	600.00

5360.17	-600.00	0.00	99.9	0.501E+00	1.57	600.00
5418.34	-600.00	0.00	99.9	0.501E+00	1.57	600.00
5476.50	-600.00	0.00	99.9	0.501E+00	1.57	600.00
5534.67	-600.00	0.00	99.9	0.501E+00	1.57	600.00
5592.84	-600.00	0.00	99.9	0.501E+00	1.57	600.00
5651.00	-600.00	0.00	99.9	0.501E+00	1.57	600.00
5709.17	-600.00	0.00	99.9	0.501E+00	1.57	600.00
5767.34	-600.00	0.00	99.9	0.501E+00	1.57	600.00
5825.50	-600.00	0.00	99.9	0.501E+00	1.57	600.00
5883.67	-600.00	0.00	99.9	0.501E+00	1.57	600.00
5941.84	-600.00	0.00	99.9	0.501E+00	1.57	600.00
6000.00	-600.00	0.00	99.9	0.501E+00	1.57	600.00

Cumulative travel time = 299208.8125 sec

Simulation limit based on maximum specified distance = 6000.00 m.
This is the REGION OF INTEREST limitation.

END OF MOD361: PASSIVE AMBIENT MIXING IN UNIFORM AMBIENT

CORMIX3: Buoyant Surface Discharges End of Prediction File

REPORT DOCUMENTATION PAGE

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14. ABSTRACT

Studies were performed to develop a new National Pollution Discharge Elimination Systems Permit for the discharge of effluents from the Pearl Harbor Naval Shipyard and Intermediate Maintenance Facility into Pearl Harbor. The technical approach adhered to proposed U.S. Environmental Protection Agency guidelines for the development and application of the following studies:

- Best Management Practices (BMP) Program
- Discharge characterization
- Water Effect Ratio (WER)
- Recalculation
- Translator

15. SUBJECT TERMS

Mission Area: Environmental Science
national pollution discharge elimination   water quality standards   copper recalculation   copper translator
water effect ratio   effluent characterization   dilution credit

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